FIRE DANGER / FIRE BEHAVIOR COMPUTATIONS WITH THE TEXAS INSTRUMENTS TI-59 CALCULATOR:

USER'S MANUAL

Robert E. Burgan

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FOREWORD

Development of a custom program for predicting fire behavior on a hand-held calculator represents an attempt to condense years of fire research by many individuals into a convenient tool for field application. Like any tool, its usefulness will grow as experience is gained.

The Texas Instruments TI-59 calculator equipped with a custom-designed chip can be used to calculate either the National Fire Danger Rating System indices or values of rate of spread, intensity, and other measurements used by Fire Behavior Officers (FBO) or fire planners. The two systems utilize different sets of fuel models. These two sets of fuel models have evolved to meet the requirements of the two different methods of application.

The NFDR System is designed to appraise the fire potential developing from weather patterns that occur during a fire season. The System applies to broad areas and represents fire conditions in exposed fuels on southwest slopes; that is, it assumes what are usually the most severe conditions. The fuel models and calculation procedures were specifically designed to reflect the seasonal variability of fire severity in both large and fine fuels. For instance, many of the NFDR fuel models have a living fuel component whose moisture variation over the season can be adjusted according to the general climate of an area. The fine fuel load is then internally transferred between the live and dead categories in response to seasonal fluctuations in the moisture content of the live fuels.

In addition, the NFDR System is designed to reflect the effect of large fuels (1000 hour timelag) on some aspects of fire behavior. These larger fuels contribute strongly to the Energy Release Component and the Burning Index. The NFDRS computations require a lot of information about the climate so that the calculations can be made automatically. The NFDR System is thus better adapted for routine calculations with much less training than is required for specific fire behavior assessments.

The fire behavior predictions system, by contrast, is designed to be used on a small scale ahead of an actual fire. The ratio of live to dead fuel is set for the time of year when fires can be severe. This system relies on considerable judgment on the part of the user to correctly determine fuel types, fuel moisture, slope, and wind along the fire front. Fires usually spread by one or more "runs", which occur when all conditions are right. During these runs, the fine fuels carry the fire. The procedures and fuel models used in fire behavior programs are designed to reflect this characteristic. Large fuel components are purposely left out of the fire behavior fuel models.

After you learn to operate the calculator with both programs, you will find that because of fewer inputs the Fire Behavior program is much simpler to use than the Fire Danger program. This may be somewhat deceiving, however, because not all procedures for projecting fire growth are accommodated within the TI-59 program. Methods for predicting mid-flame windspeed and adjusting fuel moistures for aspect, elevation, and canopy cover for different times of the day, year, and at different latitudes must precede program operation. Training is required to interpret the expected fire growth, plot it on a map, and interpret severe fire behavior. To properly use the Fire Behavior program, one should have had this training.

Fire Behavior is an extremely complex phenomenon and it cannot be expected that all the answers can be packed into a black box no matter how sophisticated it becomes. We can expect, however, that a new generation of "fire experts" who have learned to interpret conditions and utilize the latest technology and training will emerge, and become highly skilled at applying their knowledge to specific fire management situations.

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RESEARCH SUMMARY

A fire danger/fire behavior Custom Read Only Memory (CROM) has been developed for the Texas Instruments model 59 hand held calculator. This battery operated calculator can be used in either office or field situations to compute both 1978 National Fire Danger Rating (NFDR) indexes and components and several variables used to estimate wildfire behavior. Calculations can be performed in three operational modes: 1) compute NFDR indexes and components from standard NFDRS weather observations, 2) compute NFDR indexes and components using direct entry of live and dead fuel moistures, 3) perform computations required by fire behavior officers.

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INTRODUCTION

The fire danger/fire behavior Custom Read Only Memory (CROM) developed for the TI-59 calculator computes both 1978 National Fire Danger Rating (NFDR) indexes and components (Deeming and others 1977), and several of the variables used to estimate wildfire behavior. This CROM replaces all the nomograms for manually calculating NFDRS indexes and components (Burgan and others 1977) and many of the nomograms for estimating fire behavior (Albini 1976). It can perform calculations for three operational modes: 1) compute NFDR indexes and components from standard NFDRS weather observations, 2) compute NFDR indexes and components using direct entry of live and dead fuel moistures, and 3) perform fire behavior computations.

LIMITATIONS

Mathematical Fire Model

The fire behavior programs contained in the CROM are based on the fire model developed by Rothermel (1972) and are therefore subject to the limitations and assumptions specified for that model.

The fire model was designed for fires that are burning steadily in surface fuels, such as grass, brush, timber litter, and so on. The model was not designed to predict the behavior of crown fires or the influence of spot fires on fire growth. It will, however, predict when fire intensity in surface fuels is becoming severe enough to cause crowning and spotting. The fire model predicts the behavior at the fire front and assumes that the fire is burning along a line. It will not work for burning piled fuels or for predicting burnout behind the fire front. It is assumed the fire has travelled far enough so the method of ignition no longer influences behavior and that it is not impeded by fire suppression activities. Use for prescribed burning must take this into account. Fire behavior from strip firing or perimeter ignition can be quite different from the steady state condition but can be related with experience. If burning conditions are so marginal that a steady flame cannot be sustained, the model will not predict the behavior as the fire creeps through the duff and litter.

The fire model will work best in uniform fuels such as grass, long needle pine litter, clearcut slash and chaparral. Fire behavior in nonuniform fuels such as those found in many forests, particularly on mountain slopes, is more difficult to predict.

National Fire Danger Rating

The TI-59 Calculator will reduce the tedium of manual NFDRS calculations with the following limitations:

1. The calculator is not intended to replace or reduce the use of the AFFIRMS system. Automatic archiving of weather data in the National Fire Weather Library (Furman and Brink 1975), an important AFFIRMS service, is not possible with the TI-59. Use of the NFDR System for fire planning requires this long-term weather data.

2. The TI-59 is not efficient for processing large volumes of historic weather data. Thus, it neither replaces, nor provides a substitute for, the FIRDAT program (Furman and Helfman 1973).

3. Reliable fire danger ratings can be calculated only with the 20 fuel models developed for the 1978 NFDR System.

4. The TI-59 has no capability to retain data from day to day. Switching the calculator OFF erases all data entered. It was not possible to carry station data from day to day on magnetic cards because data entered from a station card would replace previously entered fuel model data. Thus, the user must manually re-enter station data each day.

5. The procedure required to exactly match the 1000-hour timelag fuel moisture (1000-H TL FM) calculation in FIRDAT and AFFIRMS would have resulted in extreme user inconvenience if applied to the TI-59. The simplified procedure used can result in slightly different 1000-H TL FM, X1000 values, and moisture content for herbaceous and woody fuels. However, the magnitude of the differences was tested and found to be a reasonable trade-off for user convenience.

6. Relative humidity is required rather than dewpoint or dry bulb and wet bulb temperatures.

7. Fuel-stick moisture must be adjusted for effects of stick aging.

8. The AFFIRMS and FIRDAT programs can compute fire danger ratings with various combinations of weather data. However, such flexibility was not attainable with the TI-59 program. All the weather inputs asked for are required.

Fire Behavior

1. Not all the graphs and tables typically used by a fire behavior officer are programmed into the CROM. Specifically, windspeed is assumed to be at midflame height; therefore, any adjustments required to reduce a 20-foot windspeed to midflame height, or to adjust it for the effects of vegetation or topography, must be done externally.

2. Although the CROM can calculate 1-hour timelag fuel moisture (1-H TL FM) from temperature, relative humidity, and cloudiness data measured on site, supplementary tables are required to determine this value for other locations.

3. Scorch height and spotting distance calculations are not programmed into the CROM.

4. The fuel models that can be used for fire behavior calculations are the 13 NFFL models described in "Estimating Wildfire Behavior and Effects" (Albini 1976). These are programmed into the CROM. Fuel models developed in the future can be entered via magnetic cards.

OPERATIONAL AIDS

Several items accompanying the TI-59 are necessary for operating the fire danger and fire behavior programs.

1. Separate plastic keyboard overlays are provided for fire danger and fire behavior. The overlays define the inputs and label the keys for entering individual data items. Labels are written above the keys to which they apply. Place the appropriate overlay on the keyboard and secure it with a small piece of tape.

Certain labels are printed on the face of the keys. Throughout this manual, the key labels will be enclosed in a rectangle: [2nd] [SBR] [R/S],...while NFDRS labels such as latitude (LAT), lightning risk scaling factor (LRSF), etc., will be identified as LAT, LRSF, and so on.

2. A plastic strip (5/8" x 3") is included that shows where to obtain fire behavior outputs. When running fire behavior, slip this card through the slot in the upper right side of the calculator so it appears in the space between the top row of keys and the display window. This strip defines the outputs obtained from keys [A] , [B] , [C] , [D] , and [E] immediately below the labels.

3. 1978 NFDRS fuel model cards can be obtained from the TI-59 program coordinator for your area. Each fuel model is recorded twice on each card--once on each side.

4. The 13 NFFL fuel models used for fire behavior are programmed into the CROM and can be accessed as explained in the section--CALCULATING FIRE BEHAVIOR.

NFDRS COMPUTATIONS FROM WEATHER DATA

Recording Form

Fire danger computations from weather data are keyed to the 10-Day Fire Danger and Fire Weather Record (Form D9b). However, because this form was designed long before the TI-59 was anticipated, not all TI-59 entries are labeled. Specifically, latitude, lightning risk scaling factor, and the number of days since the vegetation began greening up, i.e., "green days", are not labeled. Label these as LAT, LRSF, and GD in the unlabeled columns A, B, and C on the lower right corner of the form.

Definition of Inputs

The most common mode of operation will be to calculate fire danger indexes and components from weather data recorded at basic observation time and fuel moistures carried forward from the previous day. The suggested order of entry, keyboard abbreviation, item description, and location on form D9b are shown in the following tabulations.

ORDERED LIST FOR NFDRS WEATHER DATA OPTION

Entry	Data item label	Data item	Location on form D9b
1	LAT	Station latitude	Previously entered in column A
2	LRSF	Lightning risk scaling factor	From column B
3	GD	Green days	Column C. Prior to greening or after a freeze use 0. Enter 1 on the day green-up begins, 2 on the second day of green-up, 3 on the third and so on. Continue entering successively higher numbers until both herbaceous and woody vegetation go dormant as a result of a freeze, drought, or seasonal cycle; then use 0 again.
4	VEGT	Vegetation type	From D9b header information. Use 1 for annuals, 0 for perennials.
5	SLP C	Slope class	From D9b header
6	CC	Climate class	From D9b header
7	MD	Month and day	Column 1. Enter as a decimal value. For example, key in June 1 as 6.01 or June 15 as 6.15.
8	SW	State of the weather	Column 2
9	DB	Observation time dry bulb temperature	Column 3
10	RH	Relative humidity	Column 5. Relative humidity must be entered directly; it cannot be calculated from wet bulb temperature.
11[1]	OFS	Observed fuel sticks	Column 6. If not known, enter 0.
12	WS	Windspeed (in mph)	Column 12
13	YLOI	Yesterday's lightning occurrence index	Previous day's value from column 18. Use 0 for first day of calculations.
14	MRSK	Man-caused risk	Column 19. Determine as instructed in The National Fire-Danger Rating System--1978 (Deeming and others 1977) and enter the value for today.
15	MX T	Maximum temperature	Column 23
16	MN T	Minimum temperature	Column 24
17	MX RH	Maximum relative humidity	Column 25
18	MN RH	Minimum relative humidity	Column 26
19	PD	Precipitation duration	Column 31
20	LAL	Lightning activity level	Column 35
21	YM100	Yesterday's 100-H TL FM	Yesterday's value from column 36. For the first day's calculations use 10, 15, 20, or 25 for climate classes 1, 2, 3, or 4, respectively.
22	YM1000	Yesterday's 1000-H TL FM	Yesterday's value from column 40. For the first day's calculations use 15, 20, 25, or 30 for climate classes, 1, 2, 3, or 4, respectively.
23	YX1000	Yesterday's X1000 value	Yesterday's value from column 42. For the first day's calculations use the value for YM1000 as described above.
24	YHER	Yesterday's herbaceous moisture	Yesterday's value from column 43. For the first day's calculations use 10.

[1] 10-H TL FM will be calculated if a 0 is entered. However, neither the calculated value nor a measured value will be corrected for stick age.

Operating Instructions

SELECTING THE NFDRS PROGRAM AND ENTERING FUEL MODEL DATA

Slide the ON/OFF switch (located on extreme upper left corner of the calculator) to the ON position and single 0 will appear in the display.

Select the NFDRS program with the following sequence of keystrokes: [2nd] , PGM, [1] , [SBR] , [R/S] . The number 4. will appear in the display.

Choose the appropriate fuel model card. Handle the card carefully by its edges, and insert it into the lower slot on the right side of the calculator. Do not restrict its advance once it is caught by the drive motor. The display will go blank briefly, then the number 4. will appear after the fuel model card has been read. Pull the card out of the calculator.

If a flashing display results, press [CLR] , check to be sure you have a valid 1978 NFDRS fuel model card, select the NFDRS program again, and reinsert the card. If the display still flashes, the card may be dirty, resulting in a misread. Before trying to read it again, gently wash the card with warm water and a small amount of mild detergent. If it still will not read, order a new card. Misreads can also occur when operating with batteries that are nearly discharged.

After a successful read, press [R/S] and a number 1. will appear in the display.

ENTERING STATION AND WEATHER DATA

Station and weather data can be entered either sequentially or in random order. To enter data sequentially, start at the top of the ordered list described previously and enter the value for each successive item. That is, key in latitude, the first item in the ordered list, and press [SBR] LAT. This will store the latitude and position the program pointer for entry of the next item in the list, namely LRSF. Then enter the value for LRSF and press [R/S] . Continue by keying in the value for each successive item in the list, pressing [R/S] after each entry. The last entry (number 24) is yesterday's herbaceous moisture (YHRB).

Data can also be entered in random order, or the ordered list entered at any point, by keying in a valid number, pressing [SBR] and then the key below the appropriate data item label. This will store the value entered and position the program pointer for entry of the next item in the list. However, if this procedure is used, you *must always:* 1) key in the value so it appears in the display, 2) press [SBR] , 3) press the key below the DATA ITEM LABEL. Failure to press the [SBR] key can result in an error that may not be immediately obvious and can be corrected only by turning the machine off and starting all over.

CORRECTING ERRONEOUS DATA ENTRIES

If an erroneous number has been keyed into the display, finish entering that number as though it were a valid entry. Then enter the correct value in the display and press [SBR] and the DATA ITEM LABEL that corresponds to the item being corrected. For example, assume that LAT, LRSF, GD, and VEGT have been entered correctly, but that the wrong slope class (SLP C) was entered. The calculator now expects the next entry

to be climate class (CC) because that is the next item on the list. To correct the slope class, key in the proper number and press $\boxed{\text{SBR}}$ SLP C. This will move the program pointer back to slope class, store it, and reposition the pointer for entry of climate class.

CHECKING THE INPUT DATA

Prior to running the program, you may want to check some or all of the input values. Use of the $\boxed{\text{2nd}}$ key permits the same NFDRS labeled key to be used for data recall as was used for data entry. Again, you can either start at any point in the ordered NFDRS Weather Data Option list and proceed sequentially through it, or randomly access the list to check individual items. For example, to start at the beginning of the list and check each item, press $\boxed{\text{SBR}}$ $\boxed{\text{2nd}}$ LAT and the value entered for latitude will appear in the display. From this point, the remainder of the items will appear in sequence by repeatedly pressing $\boxed{\text{R/S}}$. This general procedure may be used to check any individual entry in the list by pressing $\boxed{\text{SBR}}$ $\boxed{\text{2nd}}$ DATA ITEM LABEL and then, if desired, the remainder of the items in the list by pressing $\boxed{\text{R/S}}$ repeatedly.

OBTAINING AND RECORDING NFDRS OUTPUTS

After all the station and weather data has been entered and checked, press $\boxed{\text{2nd}}$ $\boxed{\text{A}}$ to begin the calculations.

Because the NFDRS program is designed specifically for Form D9b, the outputs are keyed to the column numbers of the form. The display will flash a number, designating the column in which the next answer is to be recorded. The value to be recorded will *not* flash. For example, after pressing $\boxed{\text{2nd}}$ $\boxed{\text{A}}$, a flashing 7 will appear. This is the column number in which 10-H TL FM is to be recorded. Press $\boxed{\text{R/S}}$ to obtain the actual value to record.[2] Press $\boxed{\text{R/S}}$ again and an 8 will flash. Press $\boxed{\text{R/S}}$ and record the 1-H TL FM in column 8. Continue pressing $\boxed{\text{R/S}}$ and record each answer in the column designated by the flashing display. The procedure is designed so you must record the value of all items to be carried over to the next day (columns 36, 40, 41, 42, 43) before obtaining any NFDR indexes or components. The last value displayed will be the fire load index. If it is necessary to check any answers, the same data can be reprocessed by pressing $\boxed{\text{2nd}}$ $\boxed{\text{A}}$ and a series of $\boxed{\text{R/S}}$. Alternatively, answers can be recalled directly by pressing $\boxed{\text{RCL}}$ $\boxed{\text{X}}$ $\boxed{\text{X}}$ where $\boxed{\text{X}}$ $\boxed{\text{X}}$ is a two digit register number. See appendix B for the list of variables and their register numbers.

To process successive days of weather data, or to change one or more items in the current day's weather input list without altering the others, first press $\boxed{\text{2nd}}$ PGM $\boxed{\text{1}}$ $\boxed{\text{SBR}}$ $\boxed{\text{R/S}}$, then enter the new data. For example, to change windspeed (WS) and run the program again, press $\boxed{\text{2nd}}$ PGM $\boxed{\text{1}}$ $\boxed{\text{SBR}}$ $\boxed{\text{R/S}}$, key in the new windspeed, and press SBR WS. After this change, the revised outputs are calculated by repeating the output procedure. That is, $\boxed{\text{2nd}}$ $\boxed{\text{A}}$, then a series of $\boxed{\text{R/S}}$.

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[2] If a 10-H TL FM value was input, that same value will be output, except that it will never be less than 2. If the 10-H TL FM was entered as 0, a calculated value will appear.

A WORKED EXAMPLE

Calculate fuel moistures and the NFDRS indexes and Components using the station and weather data provided in the following example. This same example is worked on Form D9b (fig. 1) to illustrate use of this form with the program. The inputs are printed in standard type, the outputs in italics.

Step	Procedure	Enter	Press	Display
1	Turn calculator on			0
2	Select NFDRS program		[2nd] PGM [1] [SBR] [R/S]	4.
3	Enter NFDR fuel model card	Model G card		4.
4	Check fuel model compatibility		[R/S]	1.
5	Enter latitude (LAT)	49	[SBR] LAT	49.
6	Enter lgt. risk scaling factor (LRSF)	1	[R/S]	1.
7	Enter green days (GD)	22	[R/S]	22.
8	Enter veg. type (VEGT)	0	[R/S]	0.
9	Enter slope class (SLP C)	3	[R/S]	3.
10	Enter climate class (CC)	3	[R/S]	3.
11	Enter month and day (MD)	6.22	[R/S]	6.22
12	Enter state of weather (SW)	2.	[R/S]	2.
13	Enter dry bulb (DB)	87	[R/S]	87.
14	Enter relative humidity (RH)	31	[R/S]	31.
15	Enter stick moisture (OFS)	10	[R/S]	10.
16	Enter windspeed (WS)	1	[R/S]	1.
17	Enter yes. lgt. occ. index (YLOI)	2	[R/S]	2.
18	Enter man risk (MRSK)	15	[R/S]	15.
19	Enter max. temp, (MX T)	90	[R/S]	90.
20	Enter min. temp. (MN T)	48	[R/S]	48.
21	Enter max. RH (MX RH)	99	[R/S]	99.
22	Enter min. RH (MN RH)	28	[R/S]	28.
23	Enter precip. dur. (PD)	0	[R/S]	0.
24	Enter lgt. activity level (LAL)	2	[R/S]	2.
25	Enter yes. 100 H TL FM (YM100)	13.58	[R/S]	13.58
26	Enter yes. 1000 H TL FM (YM1000)	18.19	[R/S]	18.19
27	Enter yes. X1000 value (YX1000)	18.07	[R/S]	18.07
28	Enter yes. herb moisture (YHRB)	143	[R/S]	143.

Step	Procedure	Enter	Press	Display
29	Obtain col. no. for 10 H TL FM		2nd A	Flashing 7
30	Obtain 10 H TL FM		R/S	10.
31	Obtain col. no. for 1 H TL FM		R/S	Flashing 8
32	Obtain 1 H TL FM		R/S	6.
33	Obtain col. no. for 100 H TL FM		R/S	Flashing 36
34	Obtain 100 H TL FM		R/S	13.27
35	Obtain col. no. for 1000 H TL FM		R/S	Flashing 40
36	Obtain 1000 H TL FM		R/S	17.94
37	Obtain col. no. for woody moisture		R/S	Flashing 41
38	Obtain woody moisture		R/S	137.
39	Obtain col. no. for X1000 value		R/S	Flashing 42
40	Obtain X1000 Value		R/S	17.82
41	Obtain col. no. for herb moisture		R/S	Flashing 43
42	Obtain herb moisture		R/S	139.
43	Obtain col. no. for SC		R/S	Flashing 13
44	Obtain SC		R/S	3.
45	Obtain col. no. for ERC		R/S	Flashing 14
46	Obtain ERC		R/S	32.
47	Obtain col. no. for BI		R/S	Flashing 15
48	Obtain BI		R/S	26.
49	Obtain col. no. for IC		R/S	Flashing 16
50	Obtain IC		R/S	16.
51	Obtain col. no. for lgt. risk		R/S	Flashing 17
52	Obtain lgt. risk		R/S	12.
53	Obtain col. no. for LOI		R/S	Flashing 18
54	Obtain LOI		R/S	5.
55	Obtain col. no. for MCOI		R/S	Flashing 20
56	Obtain MCOI		R/S	2.
57	Obtain col. no. for FLI		R/S	Flashing 21
58	Obtain FLI		R/S	19.

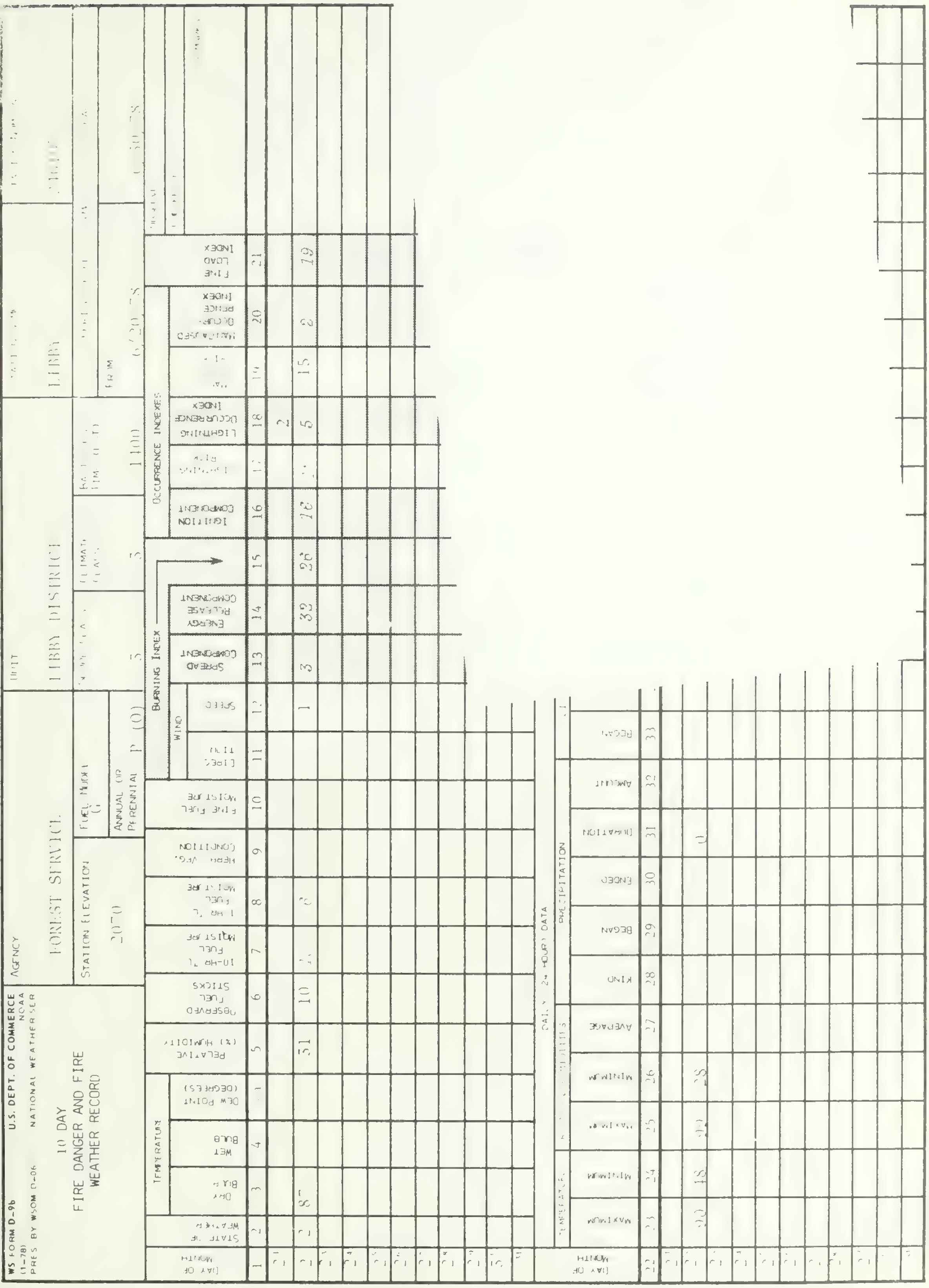

Figure 1.--Sample NFDRS computation form and worked example.

When the fire season has progressed to the point that the herbaceous fuels have cured, but the live woody fuels are not dormant (green days (GD) is not zero) today's herbaceous moisture will equal the value entered for yesterday's herbaceous moisture. This does not affect the index and component calculations.

Because the slash fuel models (models I, J, and K) have no live fuel, zero may be entered for green days, vegetation type, climate class, yesterday's X1000 value, and yesterday's herbaceous moisture. Then ignore the values calculated for herbaceous and woody fuel moisture and for the X1000 value.

If the values calculated for lightning risk and lightning occurrence index will not be used, enter zero for the lightning risk scaling factor, yesterday's lightning occurrence index, and the lightning activity level.

If the man-caused occurrence index is not needed, enter zero for man-caused risk.

NFDRS COMPUTATIONS FROM DIRECT MOISTURE INPUTS

NFDR indexes and components can be calculated from direct fuel moisture inputs and a limited amount of station and weather data, rather than from the standard weather data, if desired. The purpose is to provide a "game-playing" flexibility for research, training, or planning. For instance, you may want to know what the NFDR indexes and components would be, given assumed values for live and dead fuel moistures. Additional flexibility in selecting outputs is also available with this option.

Definitions and Entry of Inputs

The inputs required for this option depend on the desired outputs. The following table specifies the minimum data required to obtain particular NFDRS indexes and components. Each index or component requires all the inputs used previously plus those listed for the specific index or component. That is, the LIGHTNING RISK and LIGHTNING OCCURRENCE INDEX require all the data needed to compute SC, ERC, BI, and IC *plus* the LIGHTNING RISK SCALING FACTOR, YESTERDAY'S LIGHTNING OCCURRENCE INDEX and the LIGHTNING ACTIVITY LEVEL. Entry of the fuel model data is assumed.

DATA LIST FOR NFDR DIRECT MOISTURE OPTION

NFDR output	Data required	Data entry
Spread component (SC) Energy release component (ERC) Burning index (BI) Ignition component (IC)	State of weather	SW
	Slope class	SLP C
	Windspeed	WS
	1-H TL FM	1 H
	10-H TL FM	OFS
	100-H TL FM[3]	100 H
	1000-H TL FM[3]	1000 H
	Herbaceous FM[3]	HERB
	Live Woody FM[3]	WOOD
	Dry bulb temp	DB
Lightning risk and lightning occurrence index	Lightning risk scaling factor	LRSF
	Yesterday's lightning occurrence index	YLOI
	Lightning activity level	LAL
Man-caused occurrence index and fire load index	Man-caused risk	MRSK

Direct entry of the 1-H TL FM sets a flag that tells the calculator to assume *all* the required moistures will be entered directly. Thus, all moisture calculations are skipped and the first number to appear is the Spread Component. However, after the flag has been used, it is turned off by the program. THEREFORE, YOU MUST *ALWAYS* ENTER THE 1-H TL FM TO TURN THE FLAG BACK ON, *EVERY* TIME YOU USE THIS OPTION.

Values for the 1-H, 100-H, 1000-H, HERB and WOOD moistures require one additional keystroke for both entry and recall. To enter one of these values, key the number into the display, then press SBR 2nd and the key below the DATA ITEM LABEL in brackets, for example, [HERB].

Use of this option does not permit entering data in an ordered list; therefore, you *cannot* select a starting point and use the R/S key for the remainder of the entries. YOU MUST ALWAYS key the number into the display and press SBR DATA ITEM LABEL for any items also in the weather data list or SBR 2nd DATA ITEM LABEL for the direct moisture inputs. Notice that the labels for the direct moisture inputs all reference the number keys on the TI-59 keyboard. Erroneous entries of these items can be changed by keying the correct number into the display and pressing SBR 2nd DATA ITEM LABEL. To recall one of these entries, press SBR 2nd and the key below the DATA ITEM LABEL in parentheses, for example (HERB).

---

[3]These moistures required only when the fuel model being used has fuel loads in the corresponding classes.

Obtaining and Recording NFDRS Outputs

After the required data has been entered, begin program execution by pressing [2nd] [A]. The first number to appear will be a flashing 13, the D9b column number in which to record the value for Spread Component. To obtain the Spread Component, and the remainder of the indexes and components, repeatedly press [R/S]. Remember that because all the fuel moistures were entered, these calculations were skipped.

This option can be rerun by pressing [2nd] PGM [1] [SBR] [R/S], re-entering the 1-H TL FM, changing the value of other inputs if desired, then pressing [2nd] [A] and a series of [R/S].

A WORKED EXAMPLE

Calculate the NFDRS Indexes and Components using the direct inputs provided in the following example:

Step	Procedure	Enter	Press	Display
1	Turn calculator on			0
2	Select NFDRS Program		[2nd] PGM [1] [SBR] [R/S]	4.
3	Enter NFDR fuel model card	Model G card		4.
4	Check fuel model compatibility		[R/S]	1.
5	Enter lgt. risk scaling factor (LRSF)	0.8	[SBR] LRSF	0.8
6	Enter slope class (SLP C)	2	[SBR] SLP C	2.
7	Enter state of weather (SW)	0	[SBR] SW	0.
8	Enter dry bulb (DB)	67	[SBR] DB	67.
9	Enter 10 H TL FM (OFS)	8	[SBR] OFS	8.
10	Enter windspeed (WS)	0	[SBR] WS	0.
11	Enter yes. lgt. occ. index (YLOI)	0	[SBR] YLOI	0.
12	Enter man risk (MRSK)	75	[SBR] MRSK	75.
13	Enter lgt. activity level (LAL)	3	[SBR] LAL	3.
14	Enter 100 H TL FM (100 H)	10.63	[SBR] [2nd] [100 H]	10.63
15	Enter 1000 H TL FM (1000 H)	14.87	[SBR] [2nd] [1000 H]	14.87

Step	Procedure	Enter	Press	Display
16	Enter herb moisture (HERB)	20	SBR 2nd [HERB]	20.
17	Enter woody moisture (WOOD)	61	SBR 2nd [WOOD]	61.
18	Press 2nd PGM 3 SBR R/S [4]	Ignore the number that appears		
19	Press 2nd PGM 1 SBR R/S [4]	Ignore the number that appears		
20	Enter 1-H TL FM (1 H)	3.73	SBR 2nd [1 H]	3.73
21	Obtain col. no. for SC		2nd A	Flashing 13
22	Obtain SC		R/S	4.
23	Obtain col. no. for ERC		R/S	Flashing 14
24	Obtain ERC		R/S	47.
25	Obtain col. no. for BI		R/S	Flashing 15
26	Obtain BI		R/S	35.
27	Obtain col. no. for IC		R/S	Flashing 16
28	Obtain IC		R/S	27.
29	Obtain col. no. for lgt. risk		R/S	Flashing 17
30	Obtain lgt. risk		R/S	20.
31	Obtain col. no. for LOI		R/S	Flashing 18
32	Obtain LOI		R/S	10.
33	Obtain col. no. for MCOI		R/S	Flashing 20
34	Obtain MCOI		R/S	20.
35	Obtain col. no. for FLI		R/S	Flashing 21
36	Obtain FLI		R/S	32.

[4]Because this option skips several sub-programs, these steps are necessary to adjust the dry bulb temperature for the state of weather. Therefore, they must be executed whenever either the dry bulb temperature or state of weather are changed.

CALCULATING FIRE BEHAVIOR

Recording Form

The recording form developed for fire behavior officers (FBO) has been revised for use with the TI-59 and to reflect recent changes in FBO calculations. In addition a TI-59 fire behavior planning form has been developed to aid fire planning use. A sample of each form is in appendix D.

Selecting the Fire Behavior Program and A Fuel Model

If the fire danger program has been run previously, always turn the calculator off momentarily to clear the data registers before running the fire behavior program.

Program 2 is designated for fire behavior. Select this program by pressing [2nd] PGM [2] [SBR] [R/S] and a -4. will appear in the display. Because the 13 NFFL fuel models (Albini 1976) are programmed in the CROM, one of these models can now be selected by entering a model number and pressing [R/S]. The display will go blank briefly while the calculator searches for the model and loads the data into several storage registers. The model number entered will then reappear in the display. If an erroneous fuel model is keyed in, the display will flash the number entered. If this happens, press [CLR] and access Program 2 again.

Anticipating that the fire behavior fuel models built into the CROM will eventually be superceded, the program is designed to accept fire behavior fuel models from cards. When such a card becomes available, press [2nd] PGM [2] [SBR] [R/S] to obtain the -4. in the display. Put the fuel model card through the card reader and press [R/S]. The numeral 0 in the display will indicate the fuel model data has been entered.

Definition and Entry of Inputs

The inputs used for fire behavior calculations and their keyboard labels are given in the following tabulation.

FIRE BEHAVIOR INPUTS

Data	Keyboard abbreviation
Shading from clouds or canopy	SHADE
Dry bulb temperature	DB
Relative humidity	RH
1 hour timelag fuel moisture	1 H
10 hour timelag fuel moisture	10 H
100 hour timelag fuel moisture	100 H
Live fuel moisture	LIVE
Midflame windspeed in mph	M WS
Percent slope	PCT S
Projection time in hours	PT
Map scale in inches per mile	MS

Ignition component and 1-H TL FM calculations are affected by the shading of fuels at the fire site. Select the number to adjust for the effect of shading from the following:

Cloud or canopy shading	Shade value
Less than 0.1 cloud cover or no canopy	0
0.1 to 0.5 cloud or canopy cover	1
0.6 to 0.9 cloud or canopy cover	2
Total cloud or canopy cover	3

All the above inputs are mandatory, except relative humidity, which must be entered only if an estimated 1-H TL FM is to be calculated.

Operating Instructions

Unlike the entering of weather data to calculate fire danger indexes, *all* fire behavior inputs must be entered by first keying a number into the display, then pressing [SBR] DATA ITEM LABEL. Any data entry can be recalled by pressing [SBR] [2nd] DATA ITEM LABEL.

If the 1-, 10-, and 100-hour timelag fuel moistures are known, they should be entered directly. However, if they are not known, "on site" measurements of shade, dry bulb temperature, and relative humidity can be used to calculate the 1-, and 10-hour timelag fuel moistures *at that location*. To do this, first be sure the 10-H TL FM is zero by pressing [0] [SBR] 10 H. Otherwise, a previously stored or calculated 10-H TL FM can affect the current calculation. Then enter the shade value, dry bulb temperature, and relative humidity *in that order* and press [R/S]. The 1-H TL FM will be both stored and displayed, while the 10-H TL FM will be stored without display. If that 100-H TL FM is not known, press [SBR] [2nd] 10 H to display the 10-H TL FM, then store that value for the 100-H TL FM by pressing [SBR] 100 H. Dry bulb temperature and the shade value must always be entered because these values are used to calculate the IGNITION COMPONENT. Entry of relative humidity is necessary only when the above procedure is used.

The fire behavior program has no capability to adjust fuel moistures from one site to another. If this is necessary, follow the "DEAD FUEL MOISTURE ESTIMATION PROCEDURE" in the TI-59 Field Reference. Enter the value obtained as 1-H TL FM, but enter zero for both 10- and 100-hour timelag fuel moistures. The 1-H TL FM will automatically be used for all three moistures.

Obtaining Fire Behavior Outputs

The slide in key label card identifies the outputs obtained from keys [A], [B], [C], [D], and [E]. These keys *must be pressed in sequence* because results of one calculation may be used for the next. When one of these keys is pressed, the number displayed is the value for the upper item on the key label card. The value for the lower item is always obtained by pressing [R/S].

The following table provides the keystroke sequence to obtain fire behavior outputs.

Output item[5]	Abbreviation	Keystroke
Rate of spread (ch/h)	ROS	A
Heat per unit area (BTU/ft^2)	H/A	R/S
Fireline intensity (BTU/ft/s)	INT	B
Flame length (feet)	FL	R/S
Spread distance (chains)	SD	C
Map distance (inches)	MD	R/S
Perimeter (chains)	PER	D
Area (acres)	AREA	R/S
Ignition component	IC	E
Reaction intensity (BTU/ft^2/min)	IR	R/S

After a run (keys [A] through [E]) has been completed for a given set of inputs, an answer may be recalled directly from the register designated in Appendix B by pressing [RCL] and the two-digit register number or keys [A] through [E] may be pressed in sequence again.

One or more input values, including the fuel model, can be changed and the program rerun. For example, if program 2 has been accessed previously, the fuel model can be changed by pressing [SBR] [R/S], entering the new fuel model number and pressing [R/S]. Or the midflame windspeed can be changed by entering the new value, then pressing [SBR] M WS. After changing any of the other inputs, press keys [A] through [E] in sequence to rerun the program.

A WORKED EXAMPLE

Calculate fire behavior using data provided in the following example:

Step	Procedure	Enter	Press	Display
1	Turn calculator on			0
2	Select Fire Behavior Program		[2nd] PGM [2] [SBR] [R/S]	-4.
3	Select NFFL fuel model	5	[R/S]	5.
4	Enter shade value (SHADE)	3	[SBR] SHADE	3.
5	Enter dry bulb (DB)	95	[SBR] DB	95.
6	Enter relative humidity (RH)	10	[SBR] RH	10.
7	Calculate 1 H TL FM		[R/S]	2.33
8	Enter rounded 1 H TL FM (1 H)	2	[SBR] 1 H	2.
9	Enter estimated 10 H TL FM (10 H)	5	[SBR] 10 H	5.

[5]The outputs are rounded to whole numbers or to one decimal. To obtain additional significant digits, press [INV] [2nd] [(].

Step	Procedure	Enter	Press	Display
10	Enter estimated 100 H TL FM (100 H)	7	SBR 100 H	7.
11	Enter live fuel moisture (LIVE)	75	SBR LIVE	75.
12	Enter midflame windspeed (WS)	4	SBR M WS	4.
13	Enter percent slope (PCT S)	30	SBR PCT S	30.
14	Enter projection time (PT)	1	SBR PT	1.
15	Enter map scale (MS)	2	SBR MS	2.
16	Obtain rate of spread (ROS)		A	32.
17	Obtain heat/unit area (H/A)		R/S	789.
18	Obtain fireline intensity (INT)		B	469.
19	Obtain flamelength (FL)		R/S	8.
20	Obtain spread distance (SD)		C	32.4
21	Obtain map distance (MD)		R/S	0.8
22	Obtain perimeter (PER)		D	102.
23	Obtain area (AREA)		R/S	72.
24	Obtain ignition component (IC)		E	94.
25	Obtain reaction intensity (IR)		R/S	3460.

TROUBLE SHOOTING

The programming capacity of the CROM is not large enough to permit extensive checks of either your inputs or operating procedures. Therefore, if you become hopelessly lost in erroneous numbers and flashing displays, turn the calculator OFF and start from the beginning. Should your difficulties continue, write down your exact procedure and contact your TI-59 area coordinator.

BATTERY CARE

Page A-1 in the Personal Programming Guide supplied by Texas Instruments with the TI-59 specifies proper battery care. Operate the calculator as a portable unit at least twice a month; otherwise, the batteries will lose storage capacity and thus reduce operating time as a portable unit.

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APPENDIX A.

DUPLICATING FUEL MODEL CARDS

The fuel model data on one magnetic card can be recorded on another magnetic card as follows:

1. If your TI-59 is on, turn it off momentarily to be sure all data registers are set to zero.

2. Turn the TI-59 on, press [2nd] PGM [1] [SBR] [R/S] and a 4 will appear in the display.

3. Put the fuel model card to be duplicated through the card reader. This enters the data from that card into several registers in the calculator.

4. Press [2nd] [R/S] and insert the fuel model card being made through the card reader. This transfers the data from the registers in the calculator to the new fuel model card. Turn the new card over and repeat the step so the data will be recorded on both sides.

5. Label the card with the appropriate fuel model letter. Be sure to use a pen with permanent, fast-drying ink. After labeling the card, rub the ink with your finger to be sure the writing does not come off easily. Unstable ink can soil the card reader in TI-59 and cause malfunctions.

APPENDIX B.

DATA STORAGE REGISTERS

Upon completing a full set of fire danger or fire behavior calculations, the input and output data is in the following registers:

Fire Danger Rating

Data item	Reg. no.
LAT	64
LRSF	82
GD	76
VEGT	78
SLP C	80
CC	73
MD	65
SW	60
DB	61
RH	62
OFS	63
WS	79
YLOI	83
MRSK	81
MX T	67
MN T	68
MX RH	69
MN RH	70
PD	71
LAL	84
YM100	66
YM1000	72
YX1000	74
YHRB	77
1 H[1]	28
10 H	63
100 H	30
1000 H	31
WOOD	33
HERB	32
SC	48
ERC	51
BI	49
MCIC	44
LRISK	97
LOI	46
MCOI	45
FLI	50

Fire Behavior

Data item	Reg. no.
SHADE	60
DB	61
RH	62
1 H	28
10 H	63
100 H	30
LIVE	33
M WS	79
PCT S	80
PT	81
MS	82
ROS (ft/min)	48
ROS (ch/h)	88
H/A	90
INT	53
FL	54
SD	42
MD	43
PER	40
AREA	89
IC	44
IR	52

This data can be recalled by pressing RCL and the appropriate register number.

[1]The 1-H TL FM recalled from register 28 will equal the value recorded in column 8 only when the LAL equals 1 or 6.

APPENDIX C.

DEFINITION AND USE OF FIRE BEHAVIOR OUTPUTS

Fire behavior calculations will undoubtedly be performed for a variety of uses, by persons not formally trained as fire behavior officers. Therefore, the outputs and their intended uses are defined as follows:

Output	Definition	Use
Rate of spread (ch/h)	Forward rate of spread of the head fire in chains per hour	Estimate speed at which head fire will progress
Heat/unit area (BTU/ft^2)	The amount of heat released per unit area during the time that unit area is within the flaming front	Used together with rate of spread to approximate fire intensity. See figure 2.
Fireline intensity (BTU/ft/s)	Amount of heat released (in BTU's) per foot of fire front per second	A measure of fireline intensity. See table 1.
Flame length (feet)	Average length of the flame at the head of the fire	An alternate, observable measure of fireline intensity. See table 1.
Spread distance (chains)	An estimate of the probable forward movement of the head of the fire during a specified time period	Estimate position of fire front at some future time
Map distance (inches)	An estimate of the progress of the fire front for mapping purposes	Map the position of fire at some future time
Perimeter (chains)	Perimeter of the fire	Estimate forces needed to control fire
Area (acres)	Size of fire	Estimate size of fire at some future time
Ignition component (no units)	A measure of the probability of spot fires resulting from firebrands	Estimate spotting potential
Reaction intensity ($BTU/ft^2/min$)	Rate of heat released per unit area per unit time	Research

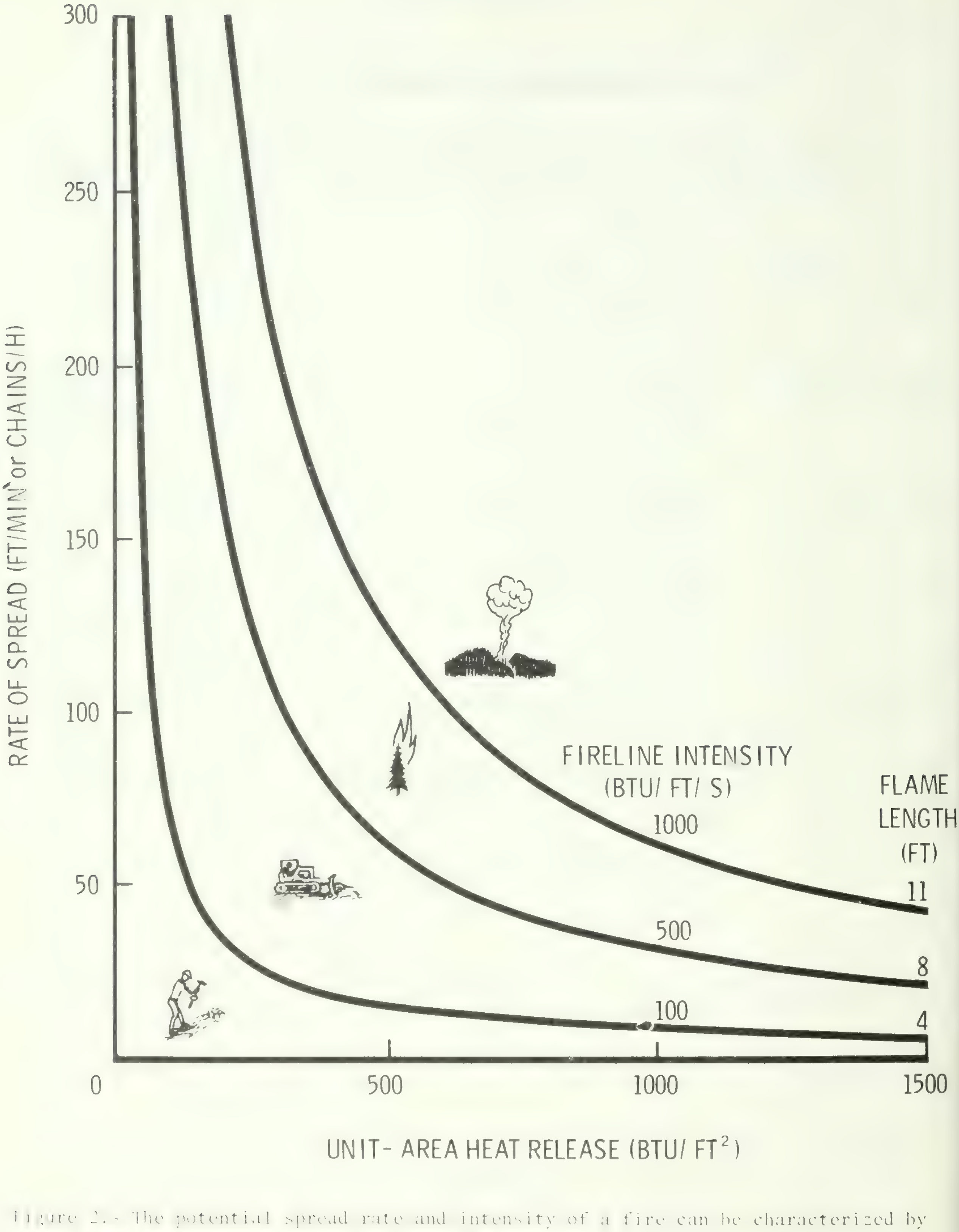

Figure 2.- The potential spread rate and intensity of a fire can be characterized by plotting unit area heat release and rate of spread.

Table 1.--*Fire suppression interpretations of fireline intensity/flamelength*

Fireline intensity / Flamelengths	Interpretation
Fireline intensity < 100 BTU/sec/ft Flamelengths < 4 feet	-fires can generally be attacked at the head or flanks by persons using hand tools. -handline should hold the fire.
Fireline intensity 100-600 BTU/sec/ft Flamelengths 4-8 feet	-fires are too intense for direct attack on the head by persons using hand tools. -handline can not be relied on to hold fire. -equipment such as dozers, pumpers, and retardant aircraft can be effective. -fires are potentially dangerous to personnel and equipment.
Fireline intensity 500-1000 BTU/sec/ft Flamelengths 8-11 feet	-fires may present serious control problems, i.e. torching out, crowning and spotting. -control efforts at the fire head will probably be ineffective.
Fireline intensities > 1000 BTU/sec/ft Flamelengths > 11 feet	-crowning, spotting, and major fire runs are probable. -control efforts at head of fire are ineffective.

APPENDIX D.

SAMPLE FIRE BEHAVIOR RECORDING FORMS

TI-59 FIRE BEHAVIOR PLANNING FORM

Name ______________________ Date ____________ Sheet ____ of ____

Purpose ____

Data item	Data item label	TI-59 reg. no.	Values		
INPUT					
Fuel model			____	____	____
Shade	SHADE	60	____	____	____
Dry bulb temperature, °F	DB	61	____	____	____
Relative humidity	RH	62	____	____	____
1 H TL FM, %	1 H	28	____	____	____
10 H TL FM, %	10 H	63	____	____	____
100 H TL FM, %	100 H	30	____	____	____
Live fuel moisture, %	LIVE	33	____	____	____
20 foot windspeed, mph			____	____	____
Midflame windspeed, mph	M WS	79	____	____	____
Windward percent slope, %	PCT S	80	____	____	____
Projection time, h	PT	81	____	____	____
Map scale, in/m	MS	82	____	____	____
OUTPUT					
A Rate of spread, ch/h	ROS	88	____	____	____
Heat per unit area, BTU/ft^2	H/A	90	____	____	____
B Fireline intensity, BTU/ft/s	INT	53	____	____	____
Flame length, ft	FL	54	____	____	____
C Spread distance, ch	SD	42	____	____	____
Map distance, in	MD	43	____	____	____
D Perimeter, ch	PER	40	____	____	____
Area, acres	AREA	89	____	____	____
E Ignition component	IC	44	____	____	____
Reaction intensity, BTU/ft^2/min	IR	52	____	____	____

Comments on fuel moisture:

Comments on windspeed:

TI-59 FIRE BEHAVIOR WORKSHEET

Name of Fire ______________ Fire Behavior Officer ______________ Sheet ____ of ____

Date ________ Time ________ Project Period Date ________ Project Time From ________ to ________

Reg.	Rate of spread (ch/h) 88	Heat/unit area (BTU/ft²) 90	Fireline intensity (BTU/s/ft) 53	Flame length (ft) 54	Spread distance (ch) 42	Map distance (in) 43	Perimeter (ch) 40	Area (acres) 89	Ignition component 44	Reaction intensity (BTU/ft²/min) 52

1. Proj. Point ____ Fuel Mod. ____ Day/Night?
2. Shade [ ] DB [ ] RH [ ] Ref.FM ____
3. Aspect ____ Corr. ____ 1 H [ ] 10/100 [ ]
4. Live [ ] 20' WS ____ Dnslp WS Corr. ____
5. Mid-flame WS [ ] Windward PCT S [ ]
6. Proj. Time (H) [ ] Map Sc (in/mi) [ ]
7. Mid-flame WS [0] Flank PCT S [ ]

1. Proj. Point ____ Fuel Mod. ____ Day/Night?
2. Shade [ ] DB [ ] RH [ ] Ref.FM ____
3. Aspect ____ Corr. ____ 1 H [ ] 10/100 [ ]
4. Live [ ] 20' WS ____ Dnslp WS Corr. ____
5. Mid-flame WS [ ] Windward PCT S [ ]
6. Proj. Time (H) [ ] Map Sc (in/mi) [ ]
7. Mid-flame WS [0] Flank PCT S [ ]

1. Proj. Point ____ Fuel Mod. ____ Day/Night?
2. Shade [ ] DB [ ] RH [ ] Ref.FM ____
3. Aspect ____ Corr. ____ 1 H [ ] 10/100 [ ]
4. Live [ ] 20' WS ____ Dnslp WS Corr. ____
5. Mid-flame WS [ ] Windward PCT S [ ]
6. Proj. Time (H) [ ] Map Sc (in/mi) [ ]
7. Mid-flame WS [0] Flank PCT S [ ]

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A fire danger/fire behavior Custom Read Only Memory (CROM) has been developed for the Texas Instruments model 59 hand held calculator can be used to compute both 1978 National Fire Danger Rating indexes and components and several variables used to estimate wildfire behavior. Calculations can be performed in three operational modes.

KEYWORDS: fire danger computations, fire behavior computation,

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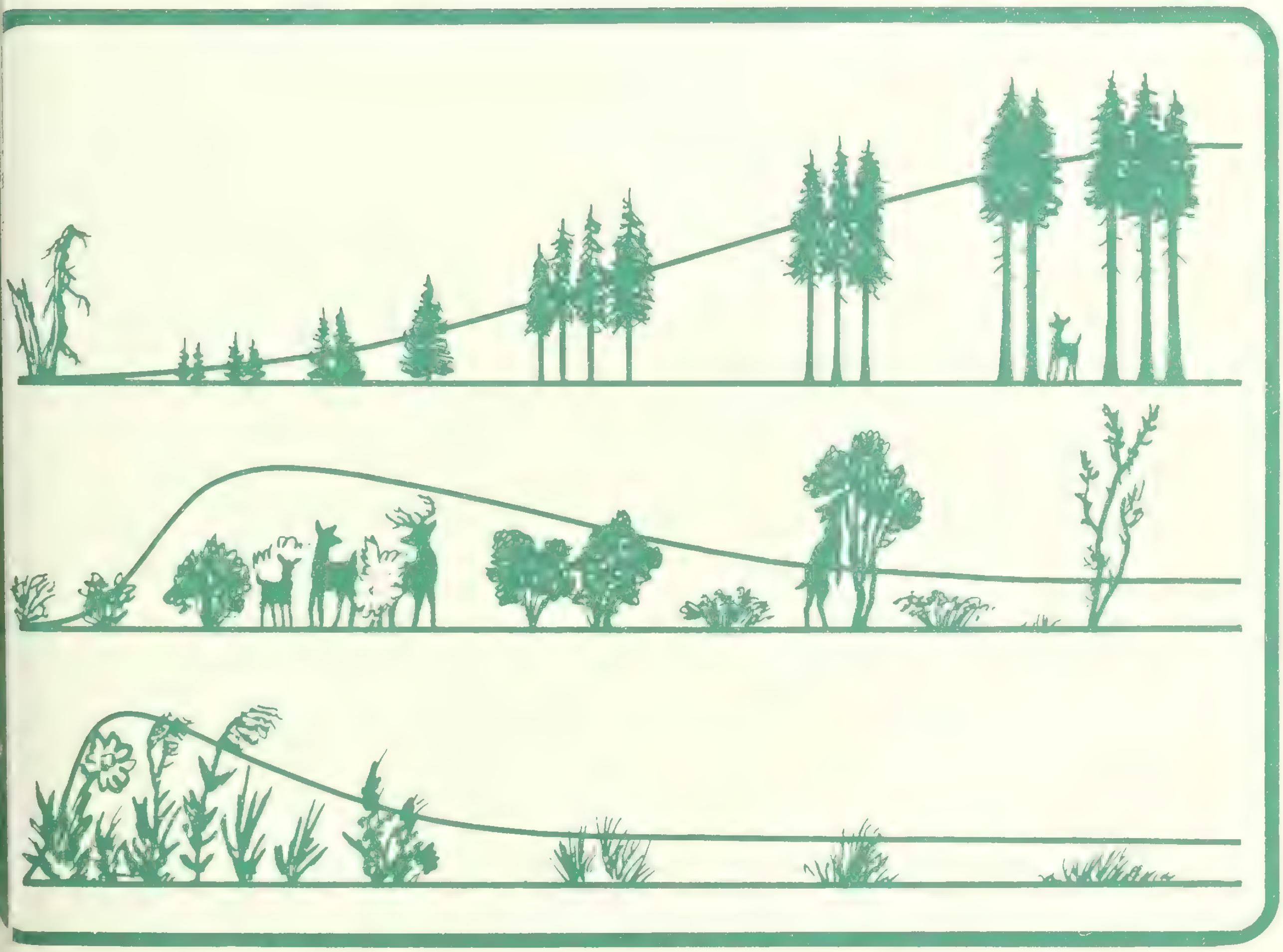
Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

- Billings, Montana
- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with University of Montana)
- Moscow, Idaho (in cooperation with the University of Idaho)
- Provo, Utah (in cooperation with Brigham Young University)
- Reno, Nevada (in cooperation with the University of Nevada)

DATA BASE FOR POST-FIRE SUCCESSION, FIRST 6 TO 9 YEARS, IN MONTANA LARCH-FIR FORESTS

PETER F. STICKNEY



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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service, U.S. Department of Agriculture

AUTHOR

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USDA Forest Service
General Technical Report INT-62
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Peter F. Stickney

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401

RESEARCH SUMMARY

Base line data on species cover (m^2/0.01 ha) and volume of space occupied (m^3/0.01 ha) for the initial 6 to 9 years of secondary forest succession for western larch-Douglas-fir forests is presented in tabular form for 20 study areas in western Montana. Disturbance treatments include wildfire and clearcutting followed by broadcast slash burning. Treatment conditions include both spring and fall burns (and summer wildfire) on both steep and gentle slopes. In addition, all cardnial exposures are represented over an elevational range from 4,300 to 5,300 feet (1,315 to 1,615 m). Location, physical description, predisturbance stand, and details of disturbance treatment are given for each site.

Information on successional development is presented in this basic form without interpretation to provide a current, quantitative resource for modelers working on forest development and related subjects and as a source for application to other forest management problems where seral changes in vegetation constitute an important planning factor.

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INTRODUCTION

Studies of forest succession in the Northern Rocky Mountains have, for the most part, been reconstructions of community change derived by sampling forest stands of different ages. This approach is a synthetic one that describes forest succession as it is perceived to be, rather than as it is observed to occur. The inherent variability between sites (stands) combined with the fragmentary record of succession time (stand ages) permits only the most generalized characterization of secondary forest succession. Additionally, the lack of a continuous record of change in composition prevents recognition of species development patterns within the succession. This is particularily true for the plants classed as "undergrowth species" (herbs and shrubs) that comprise most of the early seral vegetation.

A fundamental understanding of forest succession requires basic information on the response of component species to disturbance and subsequent successional change. Quantitative data on changes in species abundance through time provide the means for determining adaptations and responses. In most reports of forest succession for our area, the basic quantitative character of the data has been obscured in analytical treatment, and the results are presented in a form that precludes direct application to solving problems on forest wildlands.

Basic successional data has application to many forest wildland management activities. For example, the development of early seral vegetation affects the establishment and survival of planted tree seedlings, the composition and duration of big game browse ranges, the degree of vegetative cover for watershed protection, the production and accumulation of forest fuels, and the characteristics of small mammal and other wildlife habitats. The purpose of this paper is to offer basic data on composition of early seral vegetation, in a form that can be applied to forest management.

These results provide a data base for examining the initial occurrence, response, and development of individual species in terms of their area and volume. Cover (crown area) and aerial crown volume (volume of space occupied) of tree, shrub, and herb components are being sampled annually on permanent plots following prescribed broadcast burning on clearcuts and wildfire in standing timber. The tabular presentation of data represents the first 6 to 9 years of plant succession on 20 experimentally burned units at Miller Creek and Newman Ridge in northwestern Montana.

STUDY AREAS

Fourteen study areas are located at Miller Creek on the Flathead National Forest (48°31' N. latitude, 114°45' W. longitude) 18 miles (29 km) northwest of Whitefish, Montana. The remaining six study areas are at Newman Ridge on the Lolo National Forest (47°15' N. latitude, 115°20' W. longitude) 7 miles (11 km) west of St. Regis, Montana (fig. 1). Elevations at Miller Creek range from 4,300 to 4,950 feet (1,315 to 1,515 m); those as Newman Ridge range from 4,900 to 5,300 feet (1,500 to 1,615 m). The climate of both areas has been characterized by DeByle and Packer (1972) as having long, cool, wet winters and short, relatively dry summers. Annual precipitation averages about 25 inches (64 cm) at Miller Creek and nearly 40 inches (102 cm) at Newman Ridge. About two-thirds of this precipitation falls as snow. Topography at Miller Creek is gentle; the slopes are rounded by ice-sheet glaciation. Here silt-loam soils have developed on glacial till thinly mantled with loess. In contrast, at Newman Ridge slopes are steep. Soils are silt-loam developed on colluvium with a slightly thicker mantle of loess, Forests were predominantly of the larch/Douglas-fir type.

Timber volumes are evenly divided between western larch (*Larix occidentalis*), Douglas-fir (*Pseudotsuga menziesii*) and Engelmann spruce (*Picea engelmannii*). A detailed description of the study areas may be obtained from Beaufait and others (1977) and DeByle and Packer (1972).

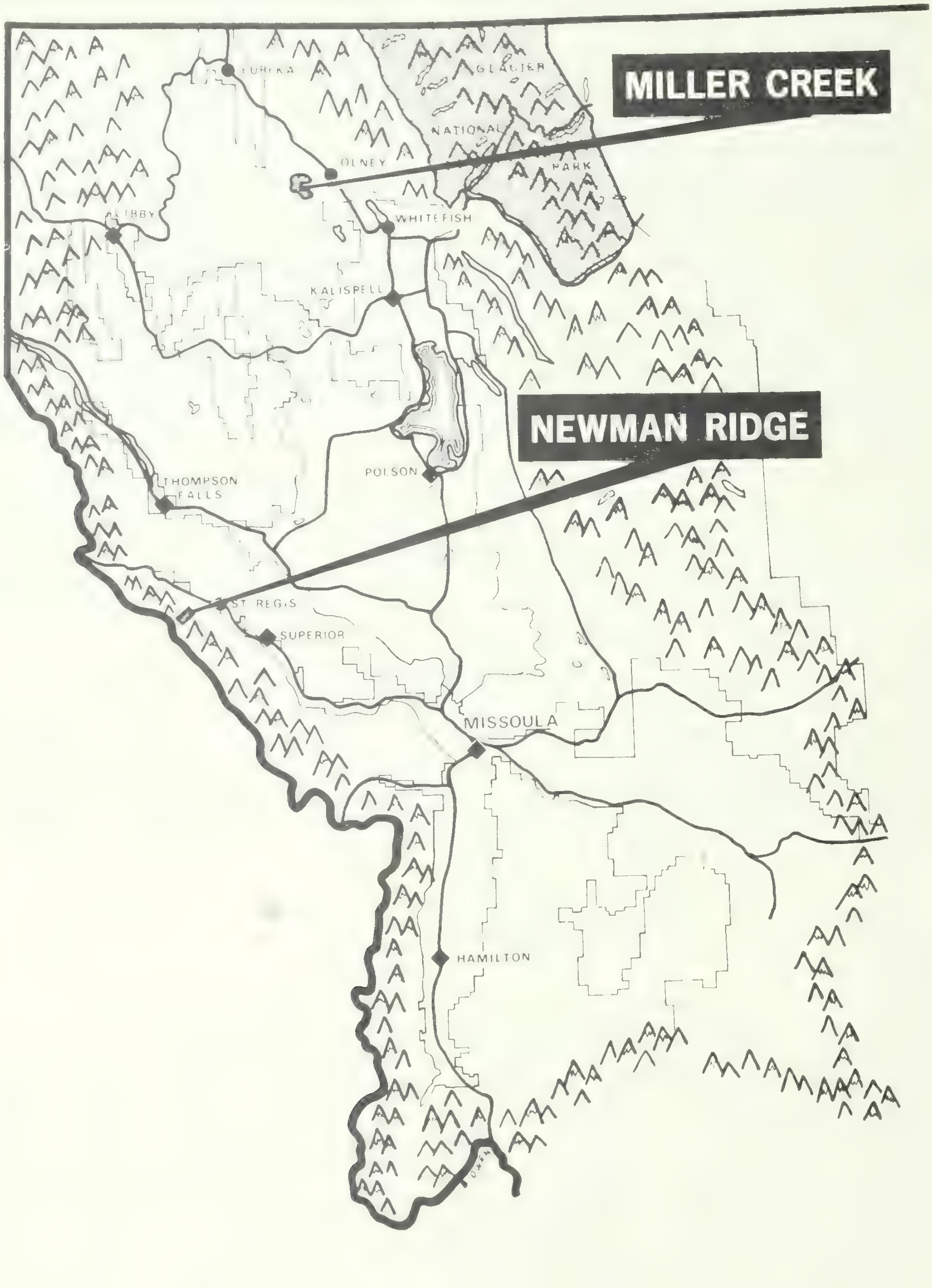


Figure 1.--Study sites on the Flathead and Lolo National Forests in western Montana (Beaufait and others 1977).

Succession study areas were superimposed on units of a study of prescribed burning (Beaufait and others 1977) aimed at relating burn character and accomplishment to fuels and weather. Burning treatments were designed to evaluate the effects of slope, exposure, and season of burning on two types of terrain. Parameters sampled in the fire study were those concerned with pre- and postburn fuels, atmospheric conditions, and burning characteristics of the fire. The units burned, which varied in size from 10 to 58 acres (4 to 23.5 ha), were clearcut-logged and then slashed to provide a uniform fuel bed. Most units were broadcast-burned within 1 year after timber harvest. The usual pattern of firing was to ignite a strip across the upper edge of the block, then the sides, and finally the lower edge. This produced an uphill-heading fire over most of the area. Most units were burned in the late afternoon or early evening. The experimental prescribed burns were conducted during "safe" burning periods, with the exception of three study areas at Miller Creek. In these areas, undisturbed forest vegetation with standing timber was unintentionally burned by a wildfire characteristic of normal burning conditions for late in a dry summer season for the Northern Rocky Mountains. The location of the succession study areas are indicated in figures 2 and 3 by the cross-hatched cutting units.

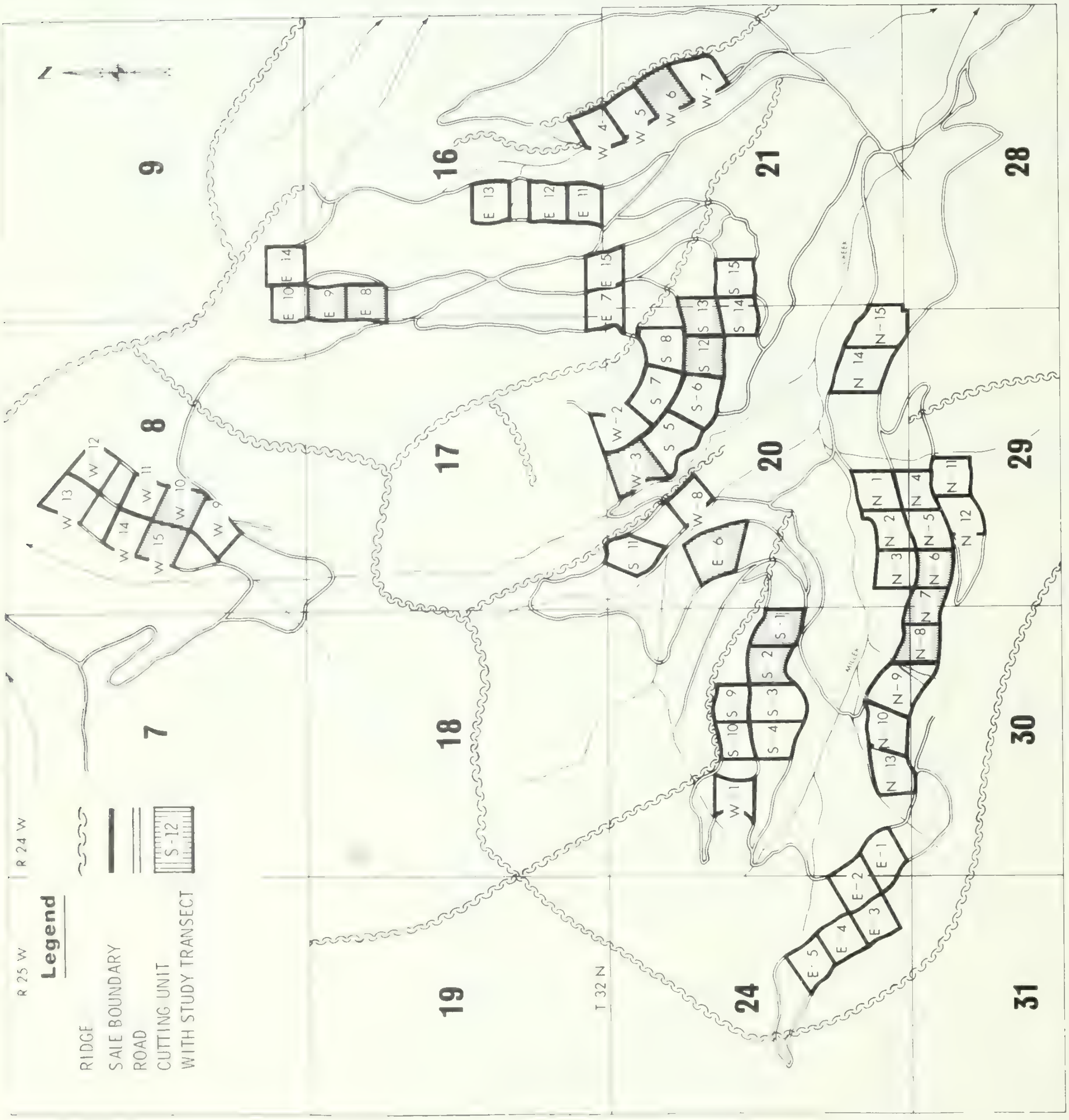
METHODS

Permanent plots and nondestructive sampling techniques were used to quantify successional development of vascular plants. This approach permits the detection of actual changes in vegetation as they occur over time. Sampling time requirements precluded the establishment of replicates within experimental burning units; thus, succession results may not always be assumed to be representative of the entire unit.

Vegetation Sampled and Plot Layout

The area sampled within a burning unit (10 to 58 acres) (4 to 23.5 ha) consisted of two 5x25-meter transects, each divided into five contiguous 5x5-meter blocks. Each block contains four sizes of nested plots (fig. 4) in which the vegetation is sampled according to height or kind (table 1). Only trees and shrubs were sampled on the three larger plots, 1.5, 3, and 5-meter squares (fig. 5). For trees taller than 2.5 meters, the d.b.h. (at 1.4 m) was measured and recorded by species to the nearest centimeter. Trees less than 2.5 meters, but taller than 1.5 meters, were counted and recorded by species and assigned an assumed diameter of 1.25 cm. Trees from 0.5 to 1.5 meters in height were counted and recorded by species. All shrubs taller than 0.5 meter and trees between 0.5 and 2.5 meters in height were measured individually (to the nearest decimeter) for two horizontal dimensions of the aerial crown and the height from the rooted point.

Herbaceous and low woody plants (including trees and shrubs less than 0.5 m in height) were sampled in two 0.5 x 0.5 meter plots nested within each block (fig. 4). Cover was visually estimated by species in units to the nearest one-sixth of the plot. Species with individual coverages of less than one-sixth were recorded as miscellaneous vegetation for that plot if they collectively totaled one-sixth of the plot area. The remaining ground surface not covered by herbaceous or low woody plants was then similarly classified for cover in order as: (1) moss, (2) litter, (3) rock, or (4) bare ground. Inasmuch as the cover estimates for this plot were designed to equal 100 percent, the cover values of these last four "ground surface" categories reflect only those portions not covered by vascular vegetation. The "representative" height within the plot of each species receiving a cover estimate was measured and recorded to the nearest half decimeter. Occurrence (absolute frequency) was also recorded for each herb and low woody plant species present within this smallest plot.


Legend
RIDGE
SALE BOUNDARY
ROAD
CUTTING UNIT WITH STUDY TRANSECT
S-12
R 25 W
R 24 W
T 32 N
7
8
9
16
17
18
19
20
21
24
28
29
30
31

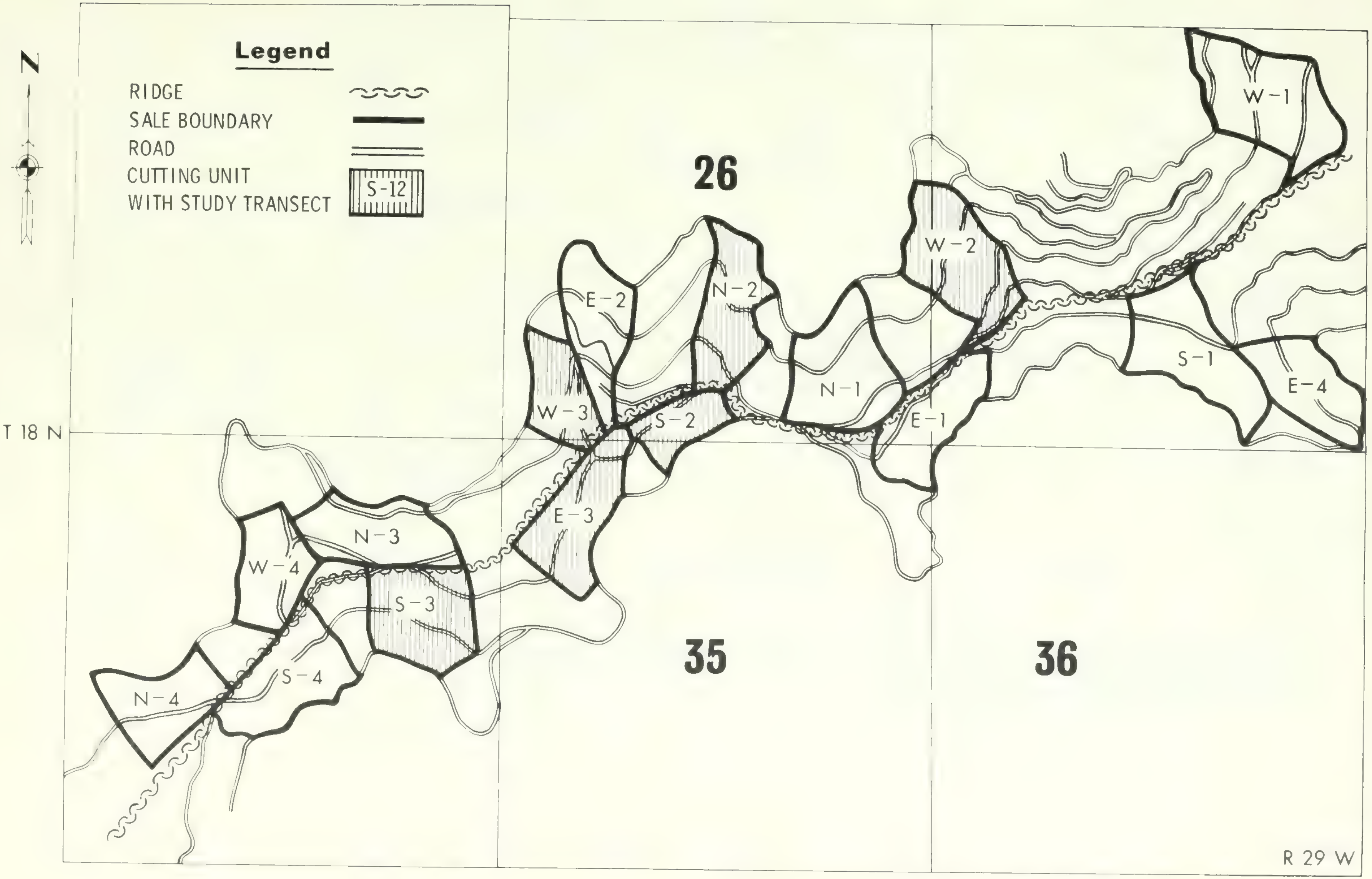


Figure 3.--Newman Ridge burning unit layout (Beaufait and others 1977). Cross-hatching designates units containing study areas.

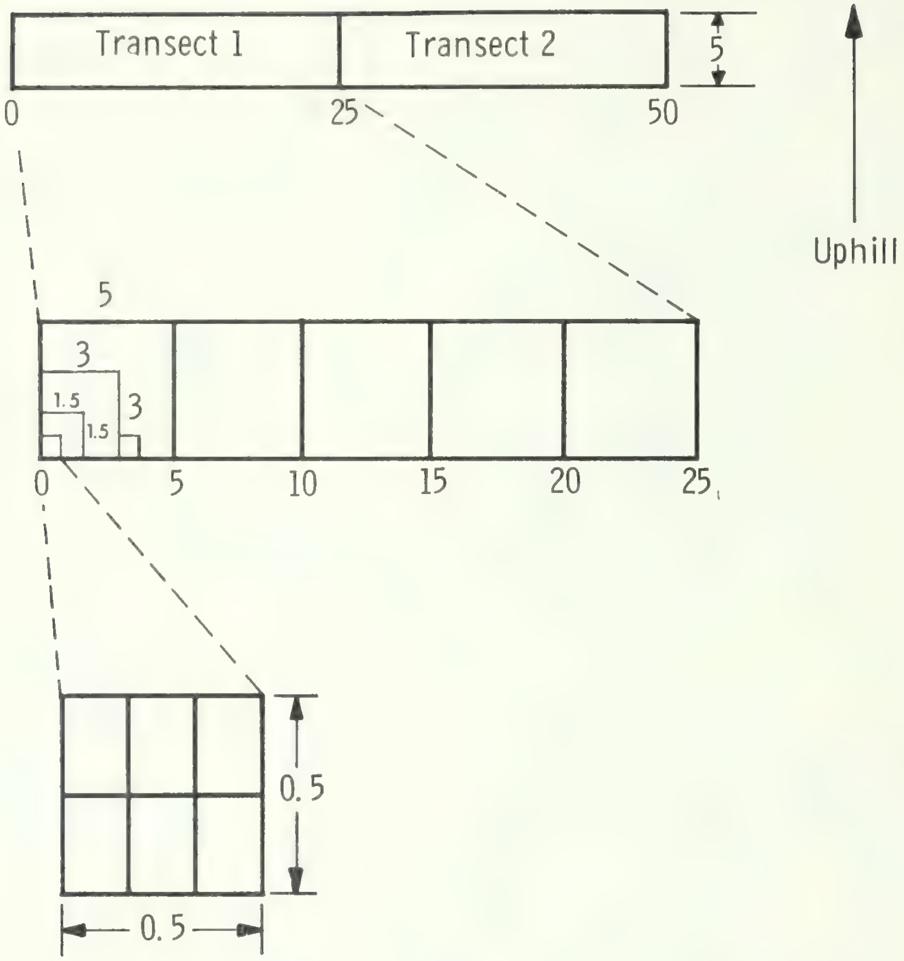


Figure 4.--Field layout of permanent transect pairs showing position and orientation of contiguous blocks and nested plots (dimensions in meters.)

Table 1.--*Summary of plots sampled on each study area*

Plot size	Height limits	Vegetation sampled	No./area
- - - - - - - - *Meters* - - - - - - -			
5 x 5	2.5 +	Trees and shrubs	10
3 x 3	1.5-2.45	Trees and shrubs	10
1.5 x 1.5	0.5-1.45	Trees and shrubs	10
0.5 x 0.5	<0.5	Trees, shrubs, low woody plants, and all herbs irrespective of height	20

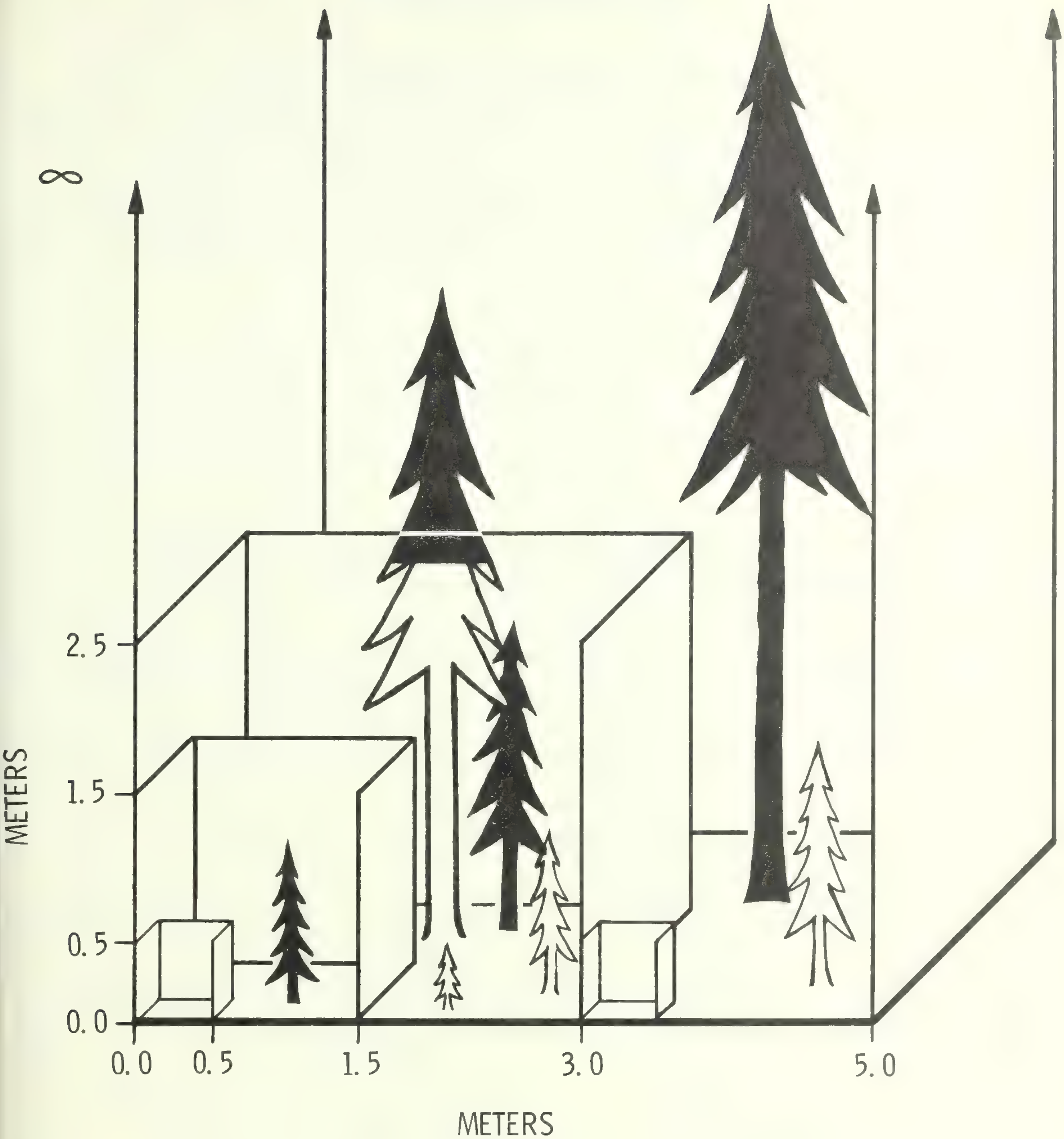


Figure 5.--Size and height limits of nested plots for sampling trees and shrubs (sample trees, dark; nonsample trees, light).

Vegetation Description

Five parameters descriptive of vegetation can be derived from this sampling method (table 2). Of these, cover (aerial crown area) and crown volume (space occupied by the aerial crown) are considered the most descriptive for characterizing vegetation development. Cover for tree and shrub species was determined by treating the two horizontal dimensions of the plant crown as axes of an ellipse and solving for area. Estimates of crown area for herbs and low woody plants, were already in appropriate form. For both kinds of samples, values for cover were averaged for each area and converted to a 0.01 hectare standard. Because this standard equals 100 square meters, the values given for cover in the tables may be read directly as either m^2/0.01 ha or percentage of ground covered.

Aerial crown volume for trees and shrubs was determined for each individual plant from crown area and plant height. The product of these values give the volume of a cylindroid representing the space occupied in the community. In a similar manner, the area and representative height of herbs and low woody plants were multiplied to determine the volume of space occupied. Volumes were averaged and converted to a m^3/0.01 ha standard.

Height is not presented as tabulated information but may be obtained by dividing the volume for any given species by its corresponding cover value. The resulting quotient is mean height in meters. This expression of vertical development is useful as an aid to identifying the periods required for various woody plants to reach mature stature within the successional progression.

Nomenclature for all vascular plants follows Hitchcock and Cronquist (1973).

Table 2.--*Parameters describing vegetation development*

Vegetative life form (height)	Parameter
Trees (1.5+ m)	Density (No./0.01 ha) Basal area (cm^2/0.01 ha)
Shrubs (0.5+ m) and trees (0.5-2.5 m)	Density (No./0.01 ha) Cover (m^2/0.01 ha) Volume (m^3/0.01 ha)
Herbs and low woody plants (including trees and shrubs <0.5 m)	Frequency (%) Cover (m^2/0.01 ha) Volume (m^3/0.01 ha)

TABULATED DATA

Content and Organization

For each study area, cover and volume data are presented in a series of six tables. Each table is accompanied by a graph illustrating its important elements. Tables 1 and 2 present cover and volume respectively of the seral community life-forms; tables 3 and 4 present species composition for cover within life form component; and tables 5 and 6 present volume. A section preceeding the tables for each study area describes location and site, forest type and tree composition, and disturbance treatment.

Some of the species included in the herb tables have traditionally been treated as shrubs. They are, in fact, "low woody plants" and lack the morphological traits characteristic of shrubs except one, the presence of perennial stems above ground in the dormant season. Their life form is such that their ecology lies with the ground layer vegetation and not with the strata of the community elevated above the forest floor. Species that have been so treated include *Berberis repens, Linnaea borealis, Chimaphila umbellata,* and *Pyrola secunda*.

Site and Treatment Information

Reference designations used for study areas, for example, Miller Creek North-6 (MC:N-6), follow those assigned by Beaufait and others (1977) to the experimental burning units. This facilitates direct reference to maps, fire, fuel, and other burning information presented by Beaufait and others. Succession study area numbers, for example, 1802-13 Area 10 (A-10), are also given to provide a ready cross reference to data summaries and facilitate communications on future results of this research.

Habitat type designations characterizing the climax forest community for each study area follow Pfister and others (1977).

Species composition of the predisturbance forest overstory is given as a percentage of the stand basal area. Tree species names are represented by a four-letter abbreviation composed of the first two letters of the genus and species of the botanical name.

The following species were recorded as trees in one or more areas:

Botanical name	Abbreviation
Abies grandis	Abgr
Abies lasiocarpa	Abla
Larix occidentalis	Laoc
Picea engelmannii	Pien
Pinus contorta	Pico
Pinus monticola	Pimo
Pinus ponderosa	Pipo
Pseudotsuga menziesii	Psme
Thuja plicata	Thpl

The information provided under disturbance treatment indicates the kinds of disturbance and also conditions and results of the fire most relevant to postfire plant succession. Data are from Beaufait and others (1977) and from unpublished records at the Forestry Sciences Laboratory and Northern Forest Fire Laboratory in Missoula. Fire intensity, characterized by heat pulse to site, was measured by weight loss from a water can integrating device. The weight values given represent mean water loss for the burning unit. The greater the loss the higher the relative fire intensity. Further information on water loss as a measure of intensity may be found in Beaufait and others (1977), Beaufait (1966), and George (1969). Duff moisture represents the water content of the upper half and lower half of the duff layer immediately before burning. Duff depth indicates the average depth remaining on the unit after burning. Data for some of the fire and fuel parameters are not available for all 20 experimental burning units.

Summary of Study Area Characteristics

Site characteristics represented in the succession profiles for the 20 study areas at Miller Creek and Newman Ridge include physical site features, vegetation type, and season burn.

Three physical features, elevation, exposure of slope, and steepness of slope, are represented. The study areas encompass a 1,000-foot (305-m) elevational range from 4,300 to 5,300 feet (1,315-1,615 m). The number of study areas falling within each 500-foot (152.4-m) contour interval is:

No. of study areas	500-foot (152.4-m) interval
1	4,000-4,450 feet (1,219.2-1,356.4 m)
14	4,500-4,950 feet (1,371.6-1,508.8 m)
5	5,000-5,450 feet (1,524.0-1,661.6 m)

All elevations above 5,000 feet are at Newman Ridge. Cardinal exposures are almost equally represented as follows:

No. of study areas	Exposure
5	North
4	East
5	South
6	West

Steepness of slope varied (5 percent intervals) from 10-60 percent. Grouped in intervals of 20 percent for gentle, moderate, and steep slope, the representation is:

No. of study areas	Slope
5	Gentle (0%-15%)
9	Moderate (20%-35%)
6	Steep (>35%)

The vegetation characterized in terms of climax forest type (Pfister and others 1977) represents four habitat types and seven phases as follows:

No. of study areas		Habitat type (phase)
1		Thuja plicata/Clintonia uniflora
	(1)	(Menziesia feruginea Phase)
4		Abies grandis/Clintonia uniflora
	(4)	(Xerophyllum tenax Phase)
14		Abies lasiocarpa/Clintonia uniflora
	(1)	(Aralia nudicaulis Phase)
	(1)	(Clintonia uniflora Phase)
	(4)	(Menziesia ferruginea Phase)
	(8)	(Xerophyllum tenax Phase)
1		Pseudotsuga menziesii/Vaccinium globulare
	(1)	(Xerophyllum tenax Phase)

The time of burning for the succession study areas extended from May through October. The number of burns by season were:

No. of study areas	Season of burn
3	Spring (May-June 21)
11	Summer (June 21-Sept. 21)
6	Fall (Sept. 21-Oct.)

Obtaining and Recording NFDRS Outputs

After the required data has been entered, begin program execution by pressing [2nd][A] . The first number to appear will be a flashing 13, the D9b column number in which to record the value for Spread Component. To obtain the Spread Component, and the remainder of the indexes and components, repeatedly press [R/S] . Remember that because all the fuel moistures were entered, these calculations were skipped.

This option can be rerun by pressing [2nd] PGM [1][SBR][R/S] , re-entering the 1-H TL FM, changing the value of other inputs if desired, then pressing [2nd][A] and a series of [R/S] .

A WORKED EXAMPLE

Calculate the NFDRS Indexes and Components using the direct inputs provided in the following example:

Step	Procedure	Enter	Press	Display
1	Turn calculator on			0
2	Select NFDRS Program		[2nd] PGM [1] [SBR] [R/S]	4.
3	Enter NFDR fuel model card	Model G card		4.
4	Check fuel model compatibility		[R/S]	1.
5	Enter lgt. risk scaling factor (LRSF)	0.8	[SBR] LRSF	0.8
6	Enter slope class (SLP C)	2	[SBR] SLP C	2.
7	Enter state of weather (SW)	0	[SBR] SW	0.
8	Enter dry bulb (DB)	67	[SBR] DB	67.
9	Enter 10 H TL FM (OFS)	8	[SBR] OFS	8.
10	Enter windspeed (WS)	0	[SBR] WS	0.
11	Enter yes. lgt. occ. index (YLOI)	0	[SBR] YLOI	0.
12	Enter man risk (MRSK)	75	[SBR] MRSK	75.
13	Enter lgt. activity level (LAL)	3	[SBR] LAL	3.
14	Enter 100 H TL FM (100 H)	10.63	[SBR] [2nd] [100 H]	10.63
15	Enter 1000 H TL FM (1000 H)	14.87	[SBR] [2nd] [1000 H]	14.87

Step	Procedure	Enter	Press	Display
16	Enter herb moisture (HERB)	20	SBR 2nd [HERB]	20.
17	Enter woody moisture (WOOD)	61	SBR 2nd [WOOD]	61.
18	Press 2nd PGM 3 SBR R/S[4]	Ignore the number that appears		
19	Press 2nd PGM 1 SBR R/S[4]	Ignore the number that appears		
20	Enter 1-H TL FM (1 H)	3.73	SBR 2nd [1 H]	3.73
21	Obtain col. no. for SC		2nd A	Flashing 13
22	Obtain SC		R/S	4.
23	Obtain col. no. for ERC		R/S	Flashing 14
24	Obtain ERC		R/S	47.
25	Obtain col. no. for BI		R/S	Flashing 15
26	Obtain BI		R/S	35.
27	Obtain col. no. for IC		R/S	Flashing 16
28	Obtain IC		R/S	27.
29	Obtain col. no. for lgt. risk		R/S	Flashing 17
30	Obtain lgt. risk		R/S	20.
31	Obtain col. no. for LOI		R/S	Flashing 18
32	Obtain LOI		R/S	10.
33	Obtain col. no. for MCOI		R/S	Flashing 20
34	Obtain MCOI		R/S	20.
35	Obtain col. no. for FLI		R/S	Flashing 21
36	Obtain FLI		R/S	32.

[4]Because this option skips several sub-programs, these steps are necessary to adjust the dry bulb temperature for the state of weather. Therefore, they must be executed whenever either the dry bulb temperature or state of weather are changed.

MILLER CREEK: North-6 (1802-13 Area 18-1)

Site location and description: NW¼NW¼ Sec. 29, T32N R24W MPM.
Elevation: 4,900 ft; Exposure: North (Az. 360°); Slope: 25%
Habitat type: Abies lasiocarpa/Clintonia uniflora, Menziesia ferruginea Phase
Predisturbance forest stand: Pien 33%, Abla 24%, Psme 24%, Laoc 20% (Stand basal area: 4,215 cm^2/0.01 ha)
Disturbance treatment: Logged August 1967; Slashed October 1967; Broadcast-burned: Sept. 10, 1968 (Succession year 1:1969); Fire intensity: 303 g water loss; Duff moisture: Upper 106%, Lower 176%; Postfire duff depth: 7.0 cm (86% of preburn depth)

Table 1-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 1-1.

Life-form component	Succession year								
	Pre	1	2	3	4	5	6	7	8
Tree	-	-	-	-	-	-	-	-	-
Shrub	90	2	8	11	13	20	20	35	29
Herb	7	6	35	35	27	26	22	36	29
Total veg.	97	8	43	46	41	46	42	71	58
Exposed ground surface:									
Bare ground	-	8	-	-	-	-	-	-	-
Rock	-	-	-	-	-	-	-	-	-
Litter	55	84	56	50	52	49	44	31	40
Moss	27	-	1	4	7	6	14	9	6

Table 1-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 1-2.

Life-form component	Succession year								
	Pre	1	2	3	4	5	6	7	8
Tree	-	-	-	-	-	-	-	-	-
Shrub	137.7	0.2	2.2	2.5	3.6	5.3	5.2	12.9	8.1
Herb	.4	.8	17.2	19.2	15.5	17.4	11.0	18.8	14.2
Total veg.	138.2	1.0	19.4	21.8	19.1	22.7	16.2	31.7	22.3

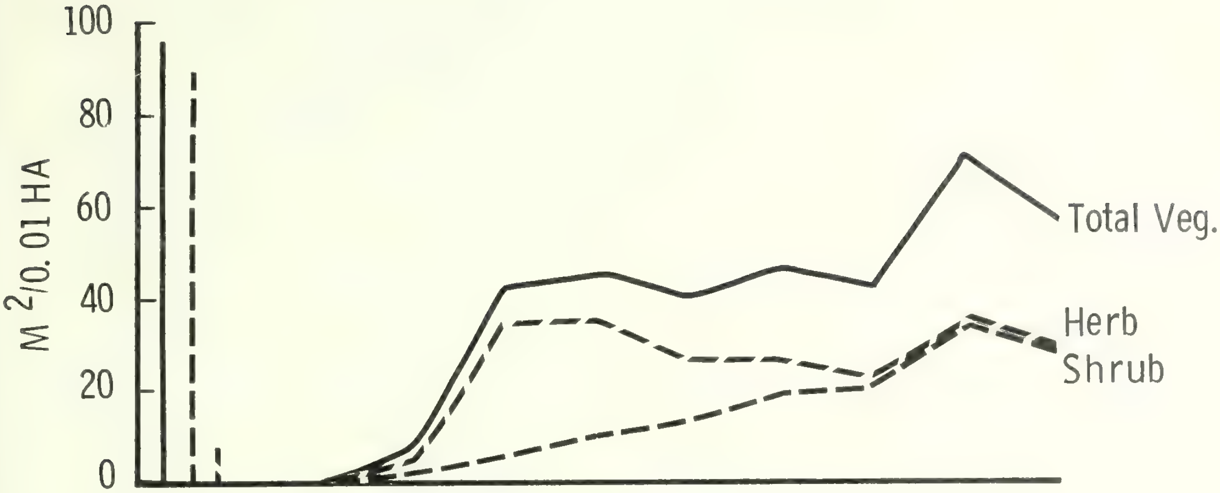


Figure 1-1. Vegetative cover.

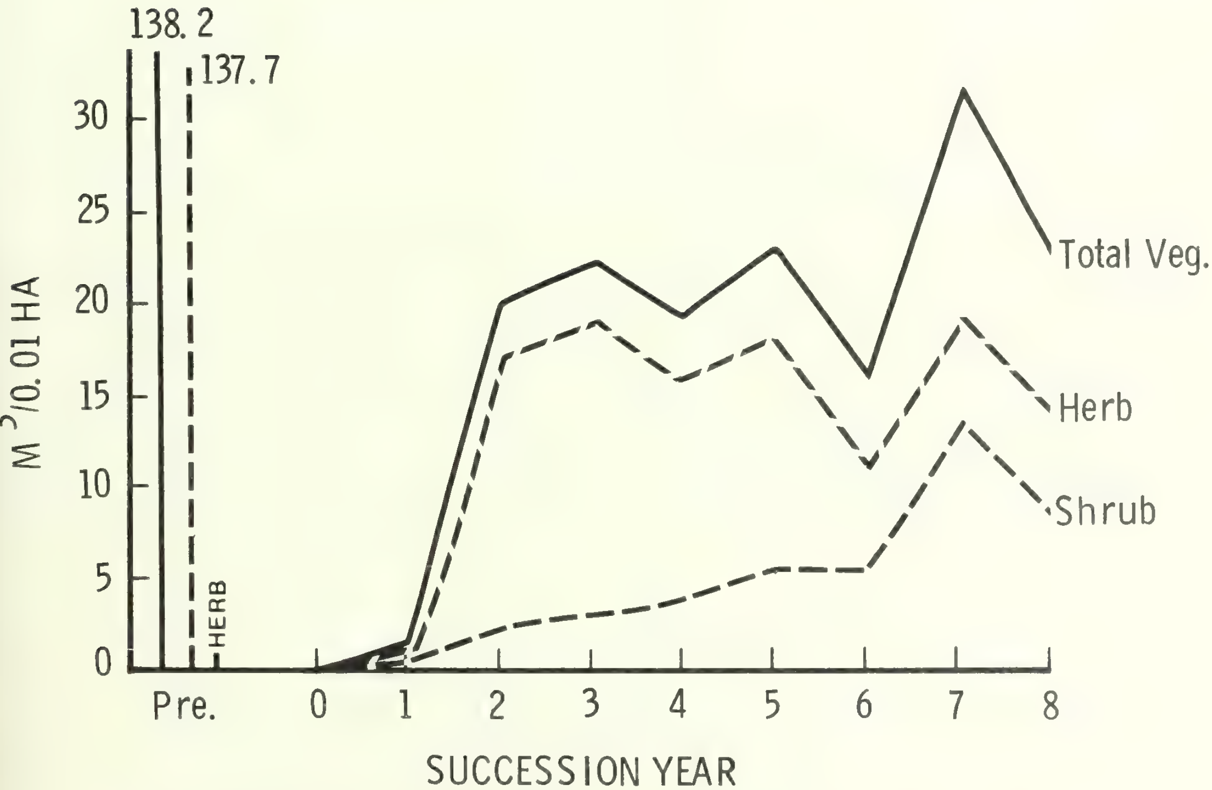


Figure 1-2. Vegetative volume.

Table 1-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 1-3.

Species	Succession year								
	Pre	1	2	3	4	5	6	7	8
Acer glabrum	5	-	-	-	-	-	-	-	-
Lonicera utahensis	1	-	-	-	-	-	-	1	1
Menziesia ferruginea	14	-	1	2	1	2	-	<1	-
Pachistima myrsinites	6	-	-	-	1	1	2	4	5
Ribes lacustre	-	-	-	1	1	1	-	-	-
Rubus parviflorus	-	2	6	5	6	11	10	15	10
Salix scouleriana	-	-	-	-	-	-	-	1	1
Taxus brevifolia	50	-	-	-	-	-	-	-	-
Vaccinium globulare	16	-	2	3	5	5	8	14	12
Total shrubs	90	2	8	11	13	20	20	35	29

Table 1-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 1-4.

Species	Succession year								
	Pre	1	2	3	4	5	6	7	8
Arnica latifolia	-	-	4	2	-	1	-	2	5
Clintonia uniflora	-	-	-	-	-	-	-	-	1
Epilobium angustifolium	-	3	29	32	24	25	21	27	21
Erigeron acris	-	-	-	-	-	-	-	1	-
Goodyera oblongifolia	1	-	-	-	-	-	-	-	-
Viola orbiculata	1	-	-	-	-	-	-	-	-
Misc. herbs	5	2	2	1	3	-	2	5	2
Total herbs	7	6	35	35	27	26	22	36	29

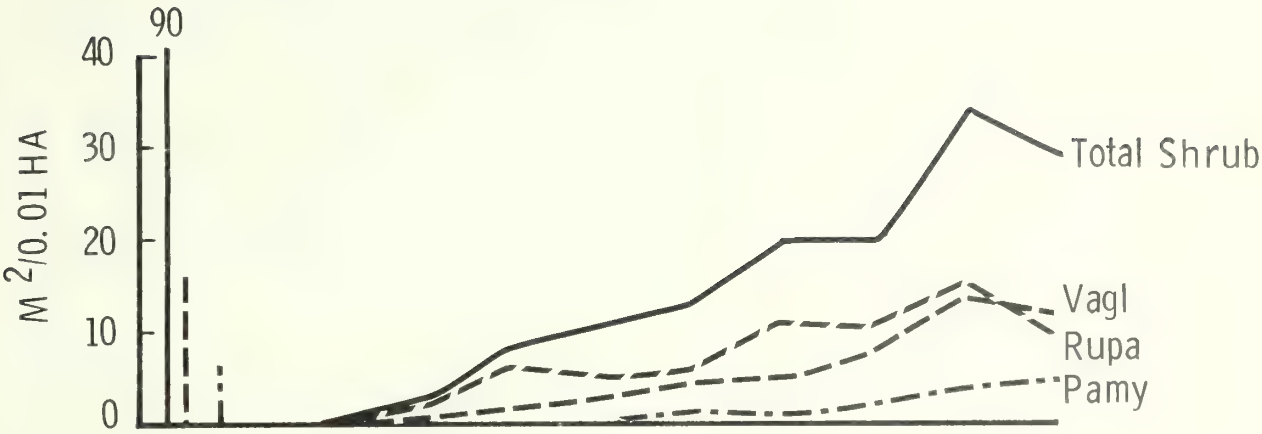


Figure 1-3. Shrub cover.

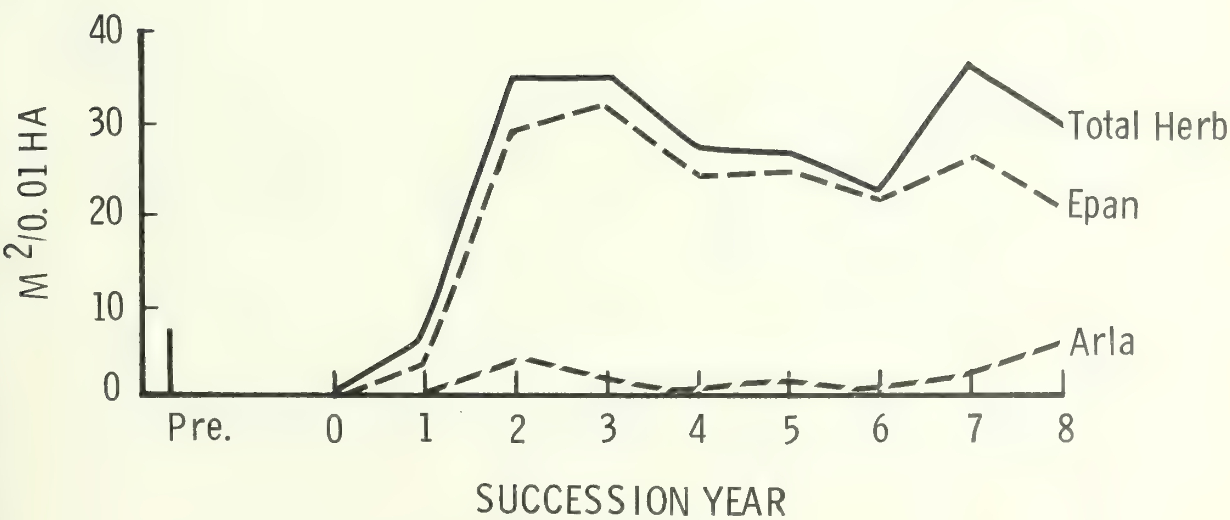


Figure 1-4. Herb cover.

Table 1-5.--Volume development of shrub component (m^3/0.01 ha), fig. 1-5.

Species	Succession year								
	Pre	1	2	3	4	5	6	7	8
Acer glabrum	16.6	-	-	-	-	-	-	-	-
Lonicera utahensis	.5	-	-	-	-	-	-	0.8	0.8
Menziesia ferruginea	17.8	-	0.2	0.7	0.3	0.7	-	.2	-
Pachistima myrsinites	.9	-	-	-	.1	.1	0.4	1.2	.6
Ribes lacustre	-	-	-	.2	.2	.2	-	-	-
Rubus parviflorus	-	.2	1.7	1.0	2.0	3.5	3.0	6.2	2.9
Salix scouleriana	-	-	-	-	-	-	-	.4	.7
Taxus brevifolia	93.0	-	-	-	-	-	-	-	-
Vaccinium globulare	9.0	-	.3	.7	1.0	.8	1.8	4.1	3.1
Total shrubs	137.7	.2	2.2	2.5	3.6	5.3	5.2	12.9	8.1

Table 1-6.--Volume development of herb component (m^3/0.01 ha), fig. 1-6.

Species	Succession year								
	Pre	1	2	3	4	5	6	7	8
Arnica latifolia	-	-	1.4	0.2	-	0.1	-	0.2	0.5
Clintonia uniflora	-	-	-	-	-	-	-	-	.1
Epilobium angustifolium	-	0.6	15.4	19.0	14.7	17.3	10.5	17.7	13.2
Erigeron acris	-	-	-	-	-	-	-	.2	-
Goodyera oblongifolia	<0.1	-	-	-	-	-	-	-	-
Viola orbiculata	<.1	-	-	-	-	-	-	-	-
Misc. herbs	.4	.2	.3	<.1	.8	-	.5	.8	.4
Total herbs	.4	.8	17.2	19.2	15.5	17.4	11.0	18.8	14.2

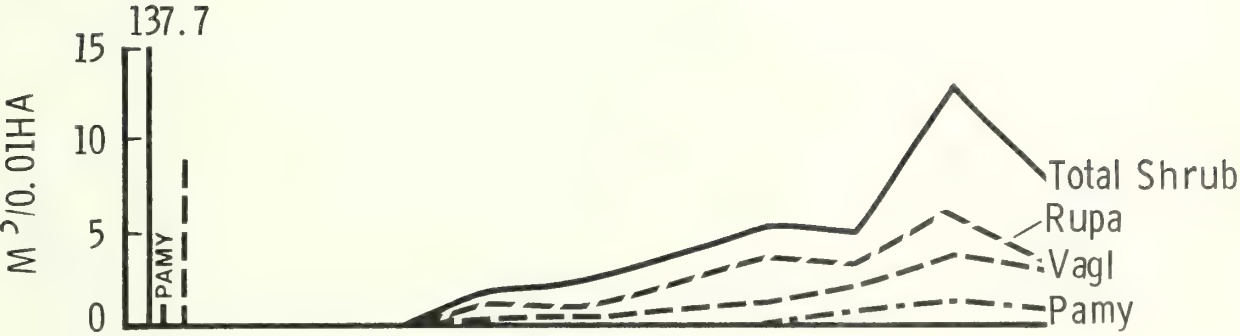


Figure 1-5. Shrub volume.

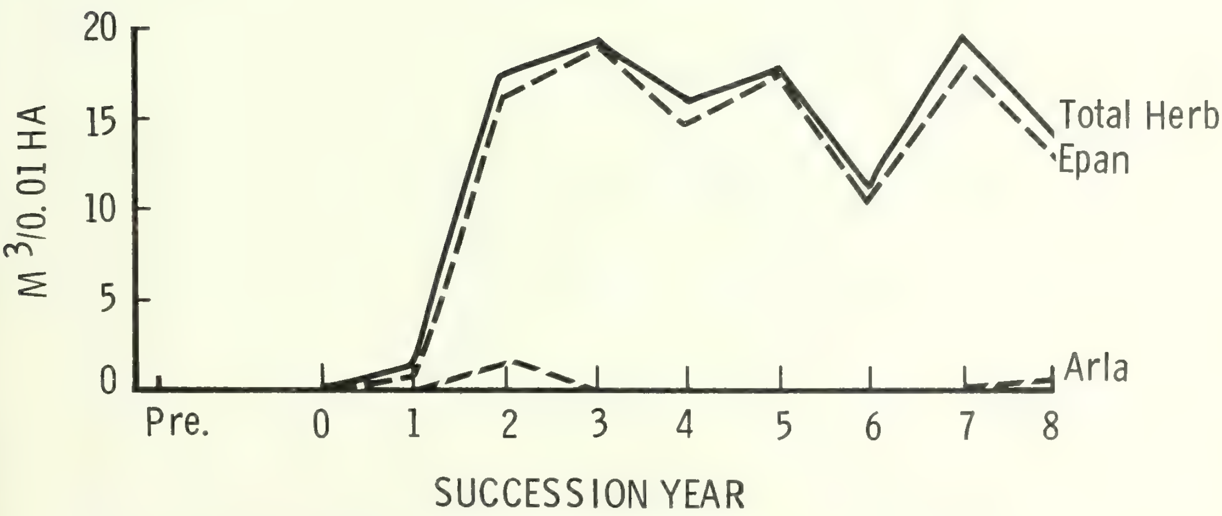


Figure 1-6. Herb volume.

MILLER CREEK: North-7 (1802-13 Area 10)

Site location and description: NE¼NE¼ Sec. 30, T32N R24W MPM.
Elevation 4,950 ft; Exposure: North (Az. 16°) Slope: 30%
Habitat type: Abies lasiocarpa/Clintonia uniflora, Menziesia ferruginea Phase
Predisturbance forest stand: Pien 63%, Abla 13%, Laoc 12%, Pico 10%, Psme 2% (Stand basal area: 6,340 cm^2/0.01 ha)
Disturbance treatment: Logged January 1967; Slashed February 1967; Broadcast-burned: June 18, 1968 (Succession year 1:1968); Fire intensity: 242 g water loss; Duff moisture: Upper 45%, Lower 194%; Postfire duff depth: 4.5 cm (51% of preburn depth)

Table 2-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 2-1.

Life-form component	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Tree	-	-	-	-	-	-	-	-	-	-
Shrub	64	-	2	9	14	11	21	27	44	41
Herb	11	-	7	49	42	42	32	31	41	32
Total veg.	74	-	10	58	56	54	53	57	85	74
Exposed ground surface:										
Bare ground	-	5	6	-	-	1	-	-	-	-
Rock	-	1	-	-	1	-	2	-	-	-
Litter	57	94	85	44	44	42	49	33	19	31
Moss	22	-	-	2	4	8	4	16	17	12

Table 2-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 2-2.

Life-form component	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Tree	-	-	-	-	-	-	-	-	-	-
Shrub	70.7	-	0.6	4.4	6.2	4.2	9.9	10.6	26.6	26.6
Herb	.8	-	1.5	28.9	21.9	21.9	21.4	14.9	24.8	19.8
Total veg.	71.5	-	2.1	33.3	28.1	26.0	31.3	25.5	51.4	46.4

MC: N-7 (A-10)

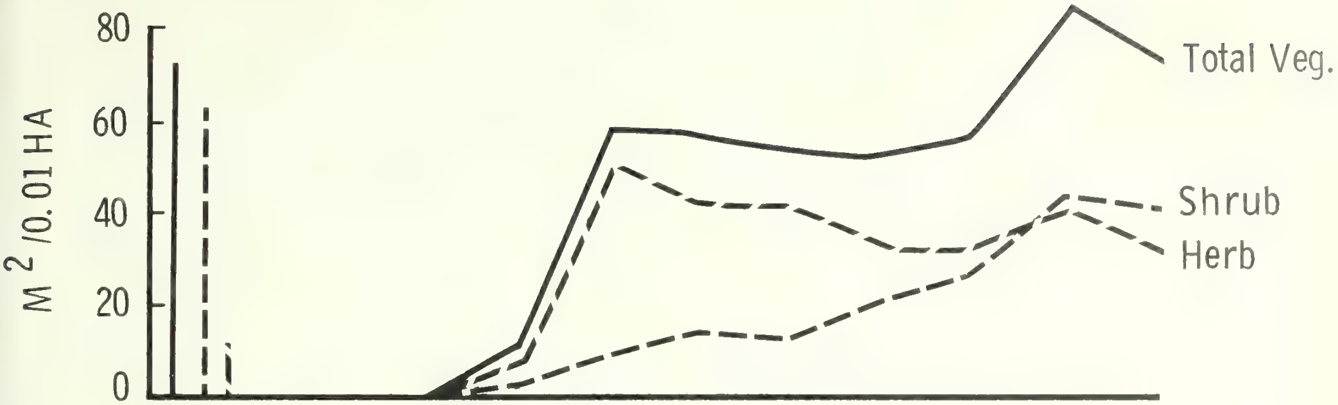


Figure 2-1. Vegetative cover.

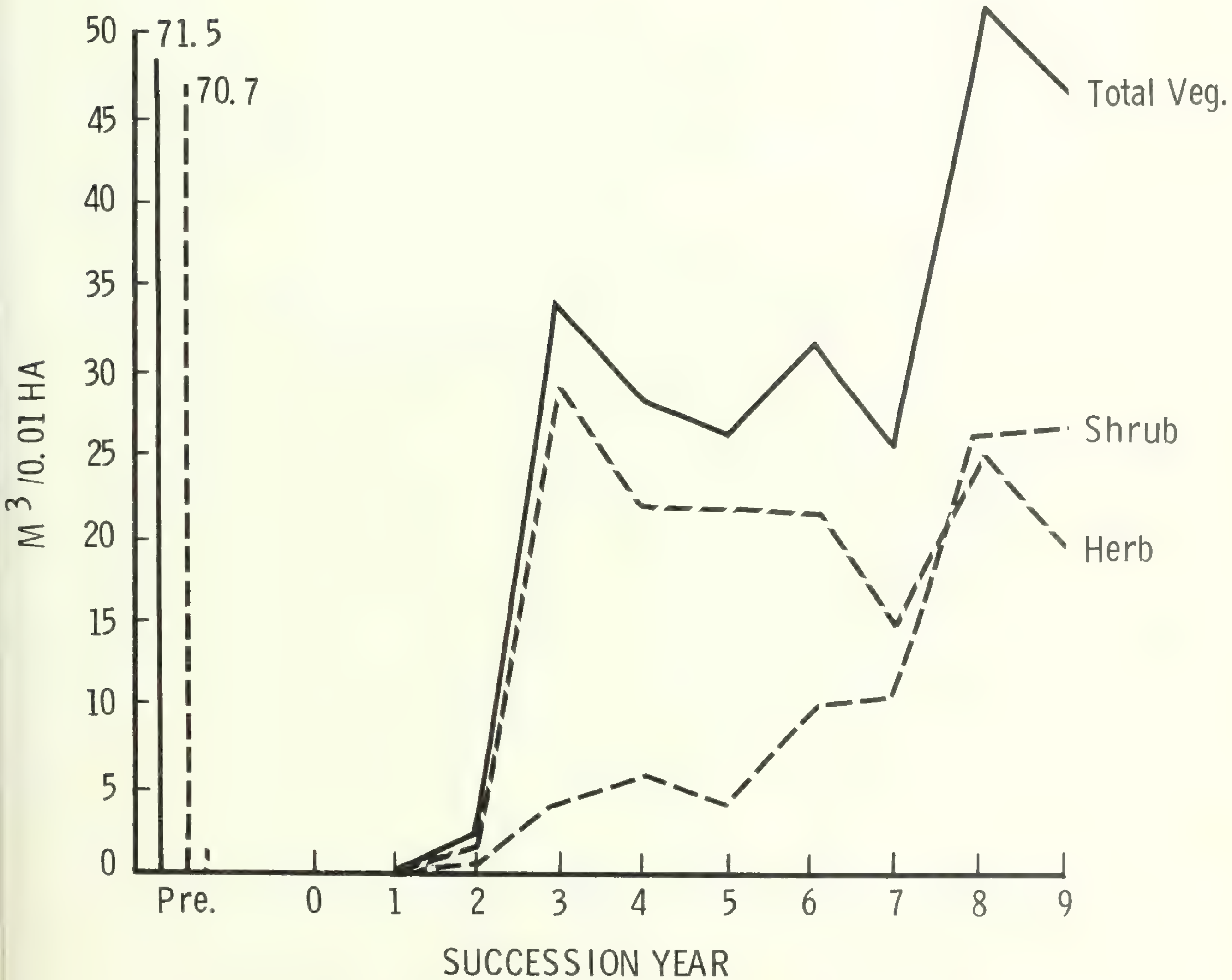


Figure 2-2. Vegetative volume.

MC: N-7 (A-10)

Table 2-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 2-3.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Alnus sinuata	4	-	<1	-	-	-	-	-	-	1
Lonicera utahensis	-	-	-	-	-	-	-	-	-	1
Menziesia ferruginea	18	-	-	-	1	1	2	2	8	4
Pachistima myrsinites	2	-	-	-	-	-	1	2	3	5
Salix scouleriana	-	-	<1	<1	-	1	3	-	6	6
Sambucus racemosa	-	-	<1	4	4	1	2	5	3	3
Taxus brevifolia	16	-	-	-	-	-	-	-	-	-
Vaccinium globulare	25	-	2	5	9	8	13	18	23	21
Total shrubs	64	-	2	9	14	11	21	27	44	41

Table 2-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 2-4.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Anaphalis margaritaceae	-	-	-	-	-	-	-	-	-	1
Arnica latifolia	-	-	1	1	1	1	-	-	2	4
Chimaphila umbellata	1	-	-	-	-	-	-	-	-	-
Clintonia uniflora	2	-	-	-	-	-	-	-	-	-
Deschampsia elongata	-	-	-	-	-	-	-	3	2	-
Epilobium angustifolium	-	-	6	39	31	36	24	24	31	25
Epilobium paniculatum	-	-	-	4	7	-	-	-	-	-
Goodyera oblongifolia	3	-	-	-	-	-	-	-	-	-
Pyrola secunda	1	-	-	-	-	-	-	-	-	-
Thalictrum occidentale	1	-	-	2	2	3	2	2	4	2
Viola orbiculata	1	-	1	1	-	-	-	-	-	-
Misc. herbs	2	-	-	2	2	2	5	1	2	-
Total herbs	11	-	7	49	42	42	32	31	41	32

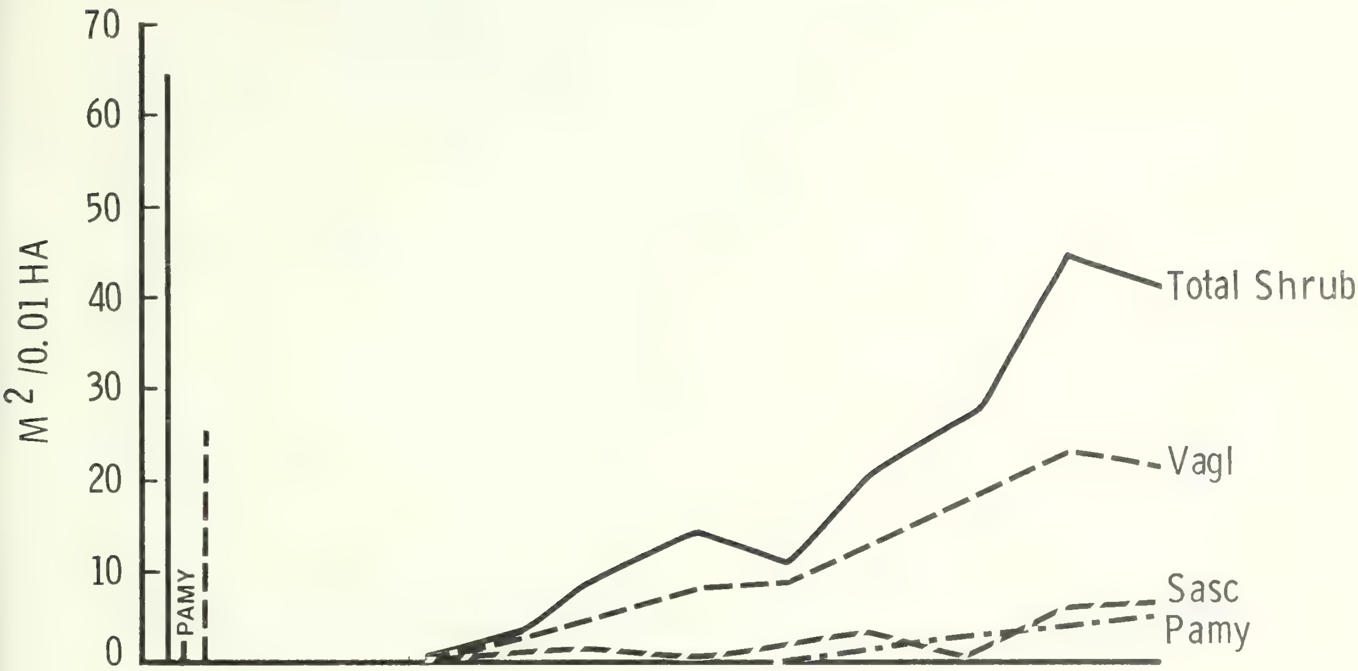


Figure 2-3. Shrub cover.

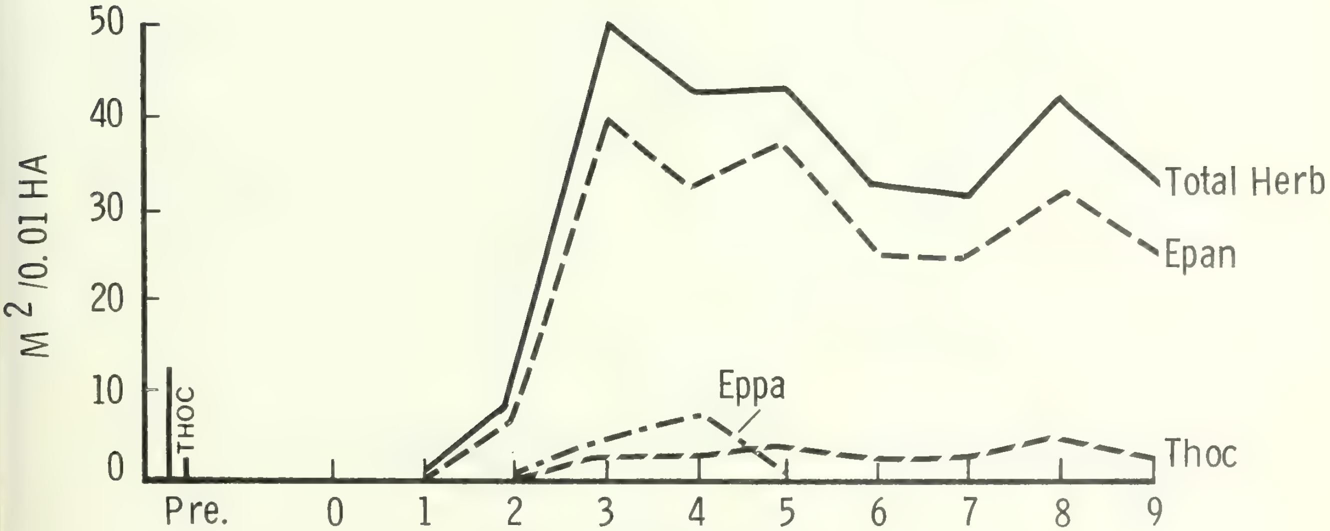


Figure 2-4. Herb cover.

Table 2-5.--Volume development of shrub component (m^3/0.01 ha), fig. 2-5.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Alnus sinuata	10.4	-	0.2	-	-	-	-	-	-	3.2
Lonicera utahensis	-	-	-	-	-	-	-	-	-	1.1
Menziesia ferruginea	24.0	-	-	-	0.5	0.8	1.6	1.3	6.7	3.2
Pachistima myrsinites	.2	-	-	-	-	-	.2	.2	.6	1.4
Salix scouleriana	-	-	0.2	0.4	-	.6	2.9	-	8.8	8.2
Sambucus racemosa	-	-	.1	3.3	3.3	.9	1.2	4.3	2.4	3.0
Taxus brevifolia	22.0	-	-	-	-	-	-	-	-	-
Vaccinium globulare	14.2	-	.2	.7	2.4	2.0	4.1	4.8	8.1	6.4
Total shrubs	70.7	-	.6	4.4	6.2	4.2	9.9	10.6	26.6	26.6

Table 2-6.--Volume development of herb component (m^3/0.01 ha), fig. 2-6.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Anaphalis margaritaceae	-	-	-	-	-	-	-	-	-	0.2
Arnica latifolia	-	-	0.2	0.2	<0.1	0.1	-	-	0.2	.6
himaphila umbellata	0.1	-	-	-	-	-	-	-	-	-
lintonia uniflora	.1	-	-	-	-	-	-	-	-	-
Deschampsia elongata	-	-	-	-	-	-	-	0.5	0.2	-
Epilobium angustifolium	-	-	1.2	23.7	19.0	20.5	19.9	13.8	23.2	18.4
Epilobium paniculatum	-	-	-	3.7	2.0	-	-	-	-	-
Goodyera oblongifolia	.2	-	-	-	-	-	-	-	-	-
Pyrola secunda	.1	-	-	-	-	-	-	-	-	-
Thalictrum occidentale	.2	-	-	.8	.5	1.0	.5	.5	.9	.5
Viola orbiculata	<.1	-	<.1	<.1	-	-	-	-	-	-
Misc. herbs	.2	-	-	.4	.4	.3	1.0	.1	.2	-
Total herbs	.8	-	1.5	28.9	21.9	21.9	21.4	14.9	24.8	19.8

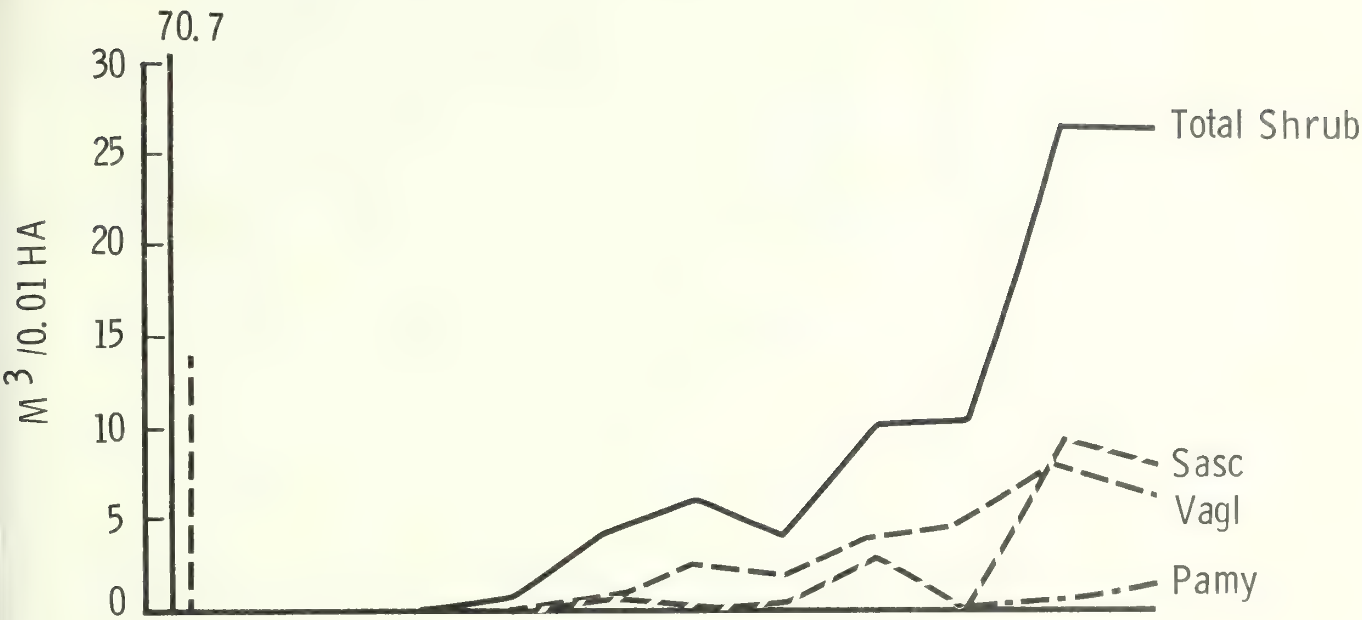


Figure 2-5. Shrub volume.

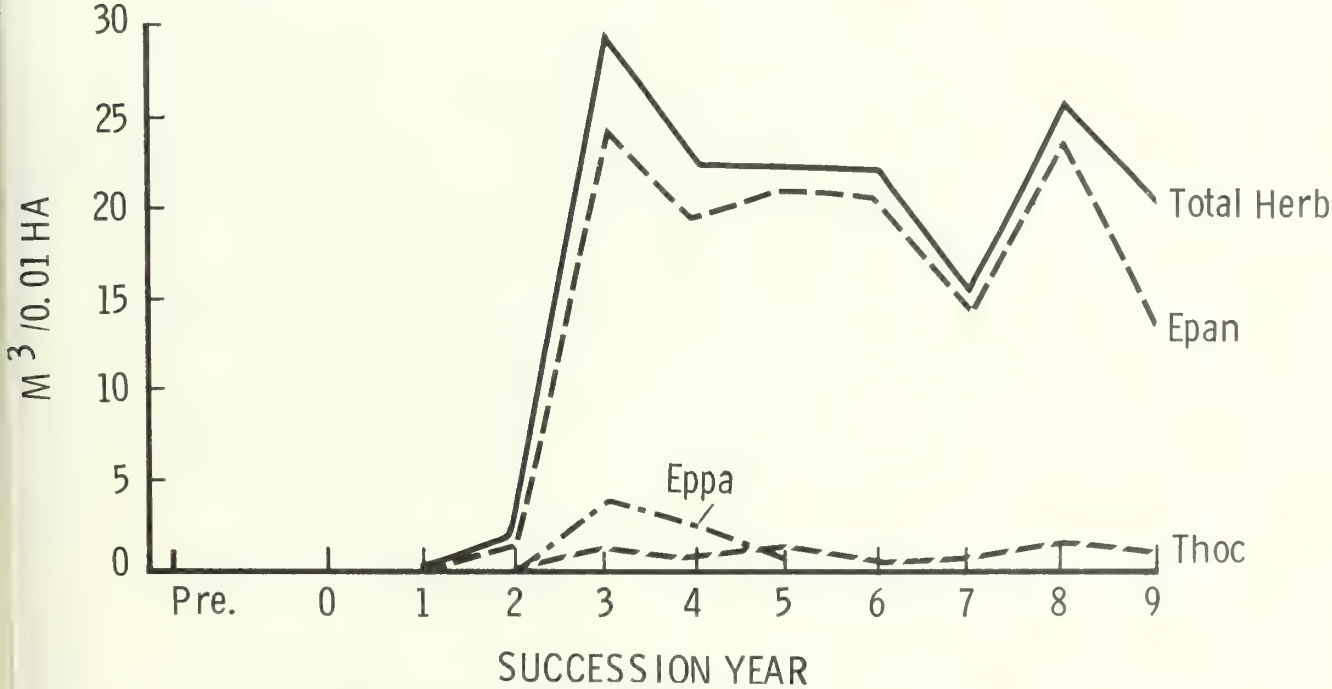


Figure 2-6. Herb volume.

MILLER CREEK: North-8 (1802-13 Area 15)

Site location and description: NE¼NE¼ Sec. 30, T32N R24W MPM.
Elevation: 4,900 ft; Exposure: Northwest (Az. 332°); Slope: 30%
Habitat type: Abies lasiocarpa/Clintonia uniflora, Menziesia ferruginea Phase
Predisturbance forest stand: Laoc 58%, Pien 21%, Abla 11%, Psme 9% (Stand basal area: 6,476 cm^2/0.01 ha)
Disturbance treatment: Logged January 1968; Slashed February 1968; Broadcast-burned: September 10, 1968 (Succession year 1:1969); Fire intensity: 266 g water loss; Duff moisture: Upper 227%, Lower 215%; Postfire duff depth: 6.0 cm (94% of preburn depth)

Table 3-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 3-1.

Life-form component	Succession year								
	Pre	1	2	3	4	5	6	7	8
Tree	-	-	-	-	-	-	-	-	<1
Shrub	69	1	11	11	14	19	19	33	38
Herb	14	16	51	38	32	26	31	47	33
Total veg.	84	17	62	50	47	45	50	80	72
Exposed ground surface:									
Bare ground	-	4	-	-	1	-	-	-	-
Rock	-	-	-	-	-	1	1	1	1
Litter	55	79	41	52	53	54	49	28	42
Moss	22	-	-	3	3	7	11	8	5

Table 3-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 3-2.

Life-form component	Succession year								
	Pre	1	2	3	4	5	6	7	8
Tree	-	-	-	-	-	-	-	-	0.3
Shrub	108.1	0.2	4.8	5.0	5.2	8.0	6.6	16.7	19.0
Herb	1.0	5.2	26.1	17.2	16.1	12.4	14.3	26.3	14.9
Total veg.	109.1	5.4	30.9	22.1	21.3	20.4	20.9	43.0	34.2

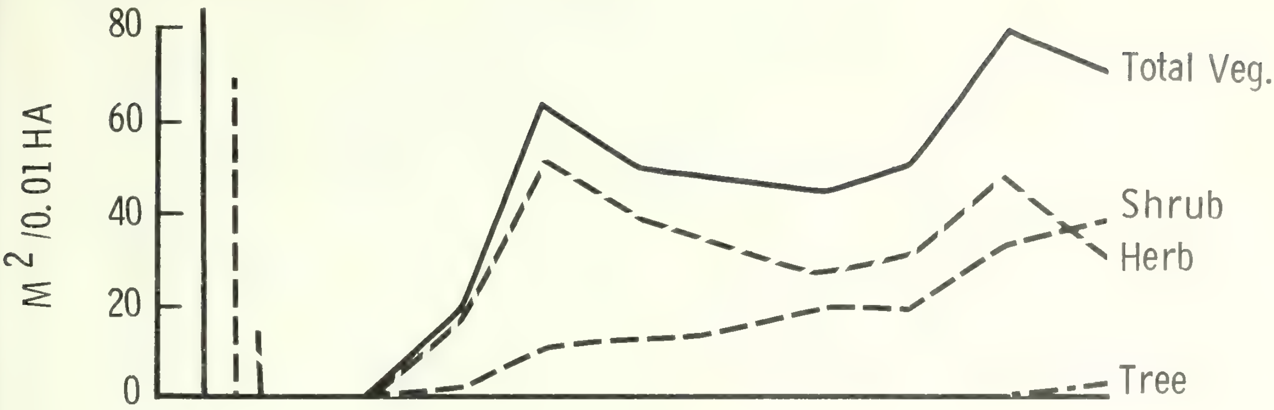


Figure 3-1. Vegetative cover.

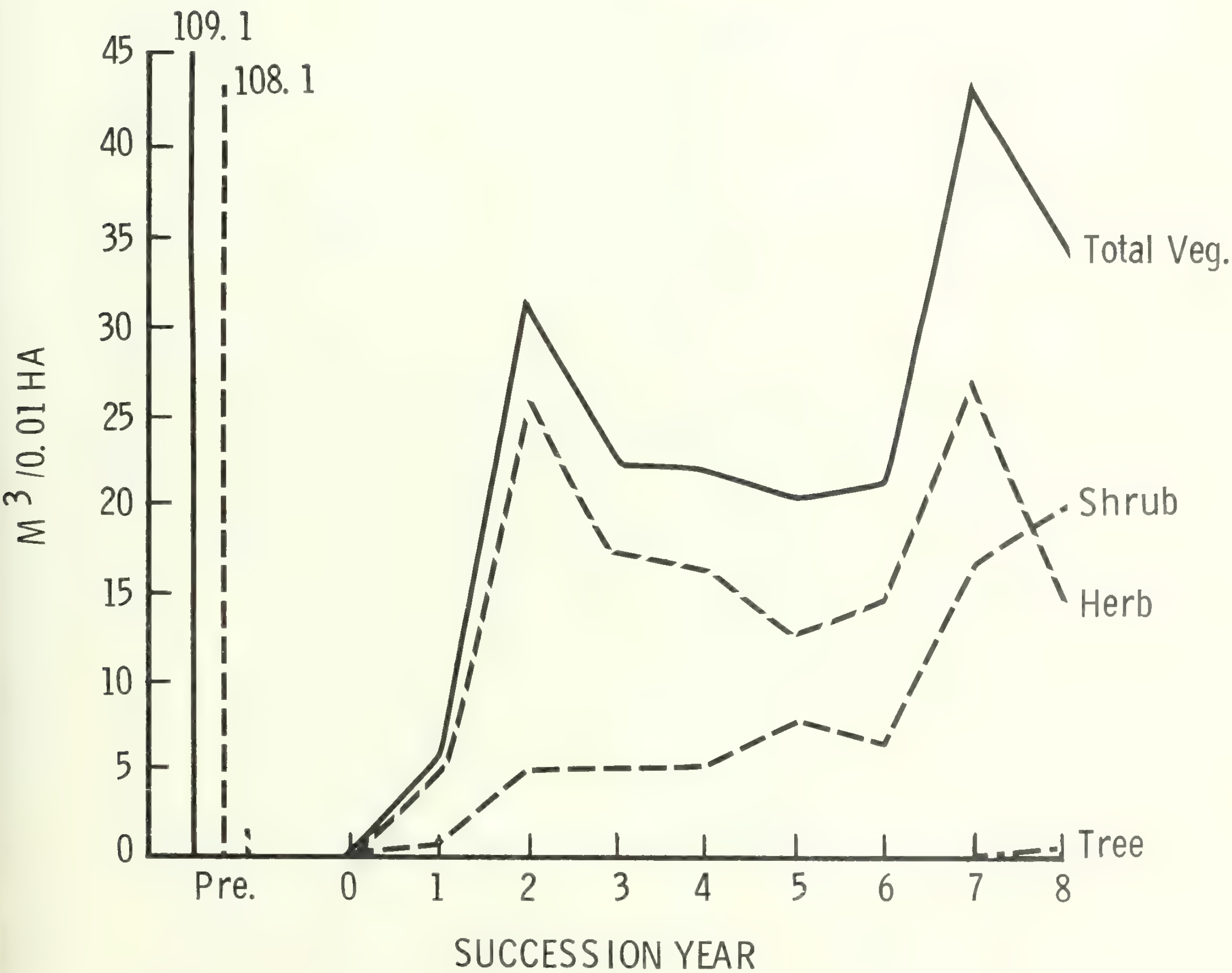


Figure 3-2. Vegetative volume.

MC: N-8 (A-15)

Table 3-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 3-3.

Species	Succession year								
	Pre	1	2	3	4	5	6	7	8
Alnus sinuata	4	-	-	-	-	-	-	-	-
Lonicera utahensis	1	-	3	4	2	2	7	5	6
Menziesia ferruginea	25	-	1	2	4	6	-	8	8
Pachistima myrsinites	2	-	-	-	-	-	1	5	4
Ribes lacustre	-	-	-	-	-	1	-	1	3
Rosa gymnocarpa	-	<1	-	-	-	-	-	-	-
Rubus parviflorus	1	1	3	1	2	2	3	6	6
Salix scouleriana	-	-	-	-	-	-	-	1	1
Sambucus racemosa	-	-	1	1	<1	-	-	1	-
Taxus brevifolia	27	-	-	-	-	-	-	-	-
Vaccinium globulare	9	-	2	3	6	8	8	8	10
Total shrubs	69	1	11	17	14	19	19	33	38

Table 3-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 3-4.

Species	Succession year								
	Pre	1	2	3	4	5	6	7	8
Arnica latifolia	4	4	11	8	4	1	-	7	5
Chimaphila umbellata	1	-	-	-	-	-	-	-	-
Clintonia uniflora	-	-	-	1	1	2	7	2	3
Epilobium angustifolium	-	10	37	28	26	20	20	35	22
Goodyera oblongifolia	1	-	-	-	-	-	-	-	-
Pyrola chlorantha	1	-	-	-	-	-	-	-	-
Viola orbiculata	2	-	-	-	-	-	-	-	-
Misc. herbs	6	2	2	1	2	3	4	2	3
Total herbs	14	16	51	38	32	26	31	47	33

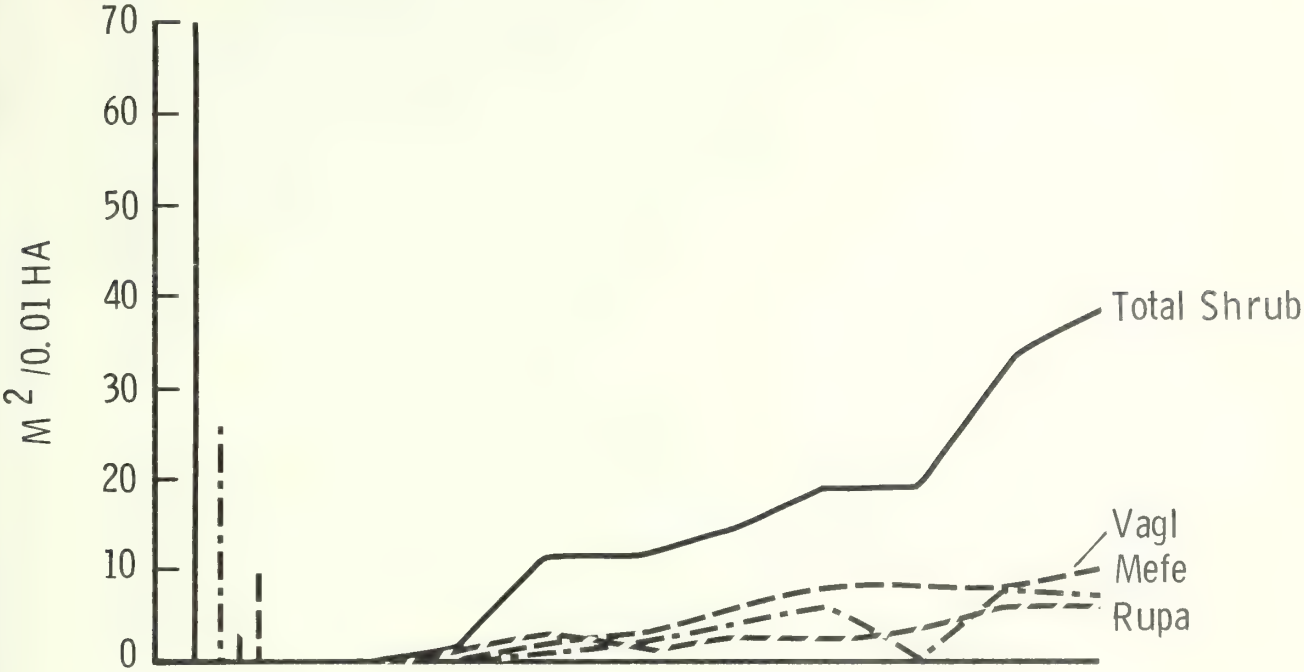


Figure 3-3. Shrub cover.

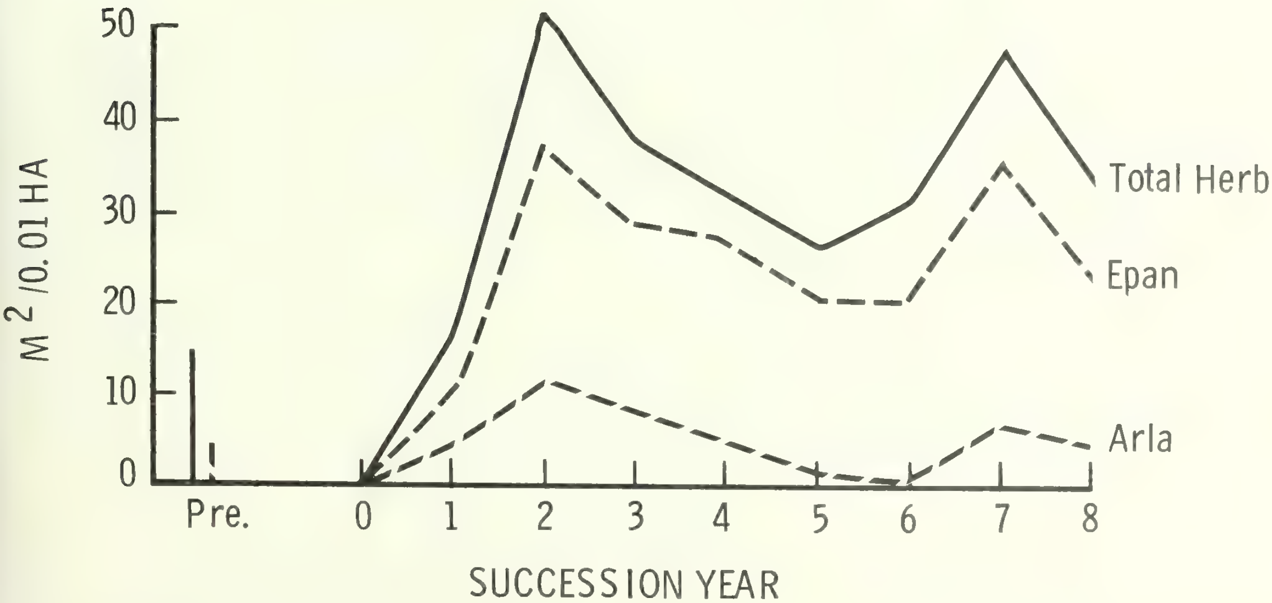


Figure 3-4. Herb cover.

Table 3-5.--Volume development of shrub component (m^3/0.01 ha), fig. 3-5.

Species	Succession year								
	Pre	1	2	3	4	5	6	7	8
Alnus sinuata	13.9	-	-	-	-	-	-	-	-
Lonicera utahensis	.1	-	1.3	1.4	1.0	0.7	4.5	3.6	3.7
Menziesia ferruginea	36.3	-	.6	1.4	2.5	4.7	-	6.9	7.5
Pachistima myrsinites	.5	-	-	-	-	-	.1	.9	1.8
Ribes lacustre	-	-	-	-	-	.7	-	.2	1.8
Rosa gymnocarpa	-	<0.1	-	-	-	-	-	-	-
Rubus parviflorus	.2	.2	1.5	.2	.5	.8	.8	1.8	2.0
Salix scouleriana	-	-	-	-	-	-	-	.3	.5
Sambucus racemosa	-	-	1.1	1.0	.2	-	-	.4	-
Taxus brevifolia	51.5	-	-	-	-	-	-	-	-
Vaccinium globulare	5.6	-	.2	1.0	.9	1.1	1.2	2.6	2.9
Total shrubs	108.1	.2	4.8	5.0	5.2	8.0	6.6	16.7	19.0

Table 3-6.--Volume development of herb component (m^3/0.01 ha), fig. 3-6.

Species	Succession year								
	Pre	1	2	3	4	5	6	7	8
Arnica latifolia	0.3	0.4	4.3	1.3	0.4	0.1	-	1.5	0.5
Chimaphila umbellata	.1	-	-	-	-	-	-	-	-
Clintonia uniflora	-	-	-	<.1	<.1	.1	4.0	.2	.3
Epilobium angustifolium	-	4.7	21.1	15.5	15.0	11.8	9.9	24.3	13.5
Goodyera oblongifolia	<.1	-	-	-	-	-	-	-	-
Pyrola chlorantha	<.1	-	-	-	-	-	-	-	-
Viola orbiculata	.1	-	-	-	-	-	-	-	-
Misc. herbs	.4	.1	.6	.2	.7	.4	.5	.2	.6
Total herbs	1.0	5.2	26.1	17.2	16.1	12.4	14.3	26.3	14.9

Figure 3-5. Shrub volume.

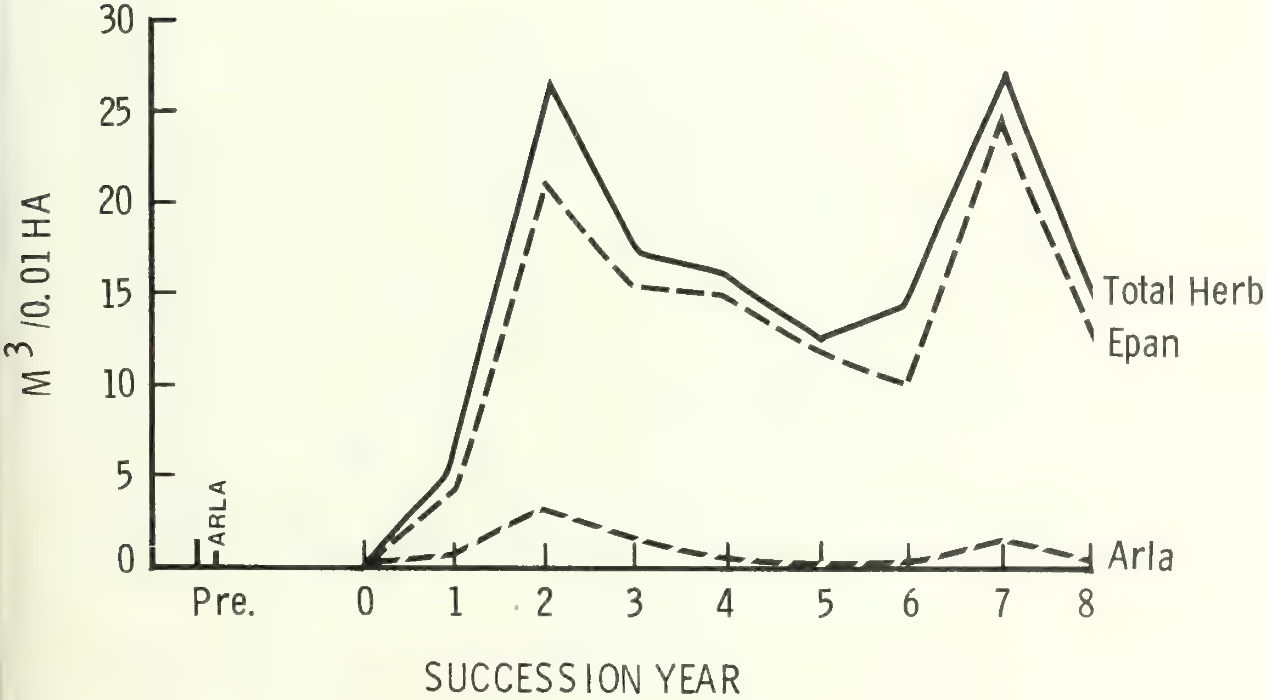


Figure 3-6. Herb volume.

MILLER CREEK: East-6 (1802-13 Area 11)

Site location and description: SW¼NW¼ Sec. 20, T32N R24W MPM.
Elevation 4,750 ft; Exposure: Northeast (Az. 36°) Slope: 20%
Habitat type: Abies lasiocarpa/Clintonia uniflora, Clintonia uniflora Phase
Predisturbance forest stand: Laoc 52%, Abla 38%, Pien 10% (Stand basal area: 2,945 cm^2/0.01 ha)
Disturbance treatment: Logged June 1967; Slashed June 1967;
Broadcast burned: October 2, 1967 (Succession year 1:1968);
Fire intensity: 243 g water loss; Duff moisture: Upper 96%, Lower 70%; Postfire duff depth: 2.7 cm (51% of preburn depth)

Table 4-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 4-1.

Life-form component	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Tree	-	-	-	-	-	-	-	1	1	6
Shrub	113	1	-	2	2	3	5	14	21	23
Herb	25	42	52	49	33	32	27	27	43	37
Total veg.	138	43	52	51	35	35	31	41	65	65
Exposed ground surface:										
Bare ground	-	6	3	7	1	1	1	-	2	-
Rock	-	-	1	1	1	-	2	-	1	1
Litter	44	50	41	34	45	44	47	34	23	23
Moss	22	1	3	8	18	20	18	28	20	24

Table 4-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 4-2.

Life-form component	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Tree	-	-	-	-	-	-	-	0.4	0.1	6.1
Shrub	218.2	0.1	-	0.3	0.4	0.8	1.6	5.9	12.4	13.4
Herb	3.1	7.3	26.9	28.4	14.5	16.4	8.8	9.1	17.6	14.8
Total veg.	221.3	7.4	26.9	28.7	15.0	17.2	10.4	15.4	30.2	34.3

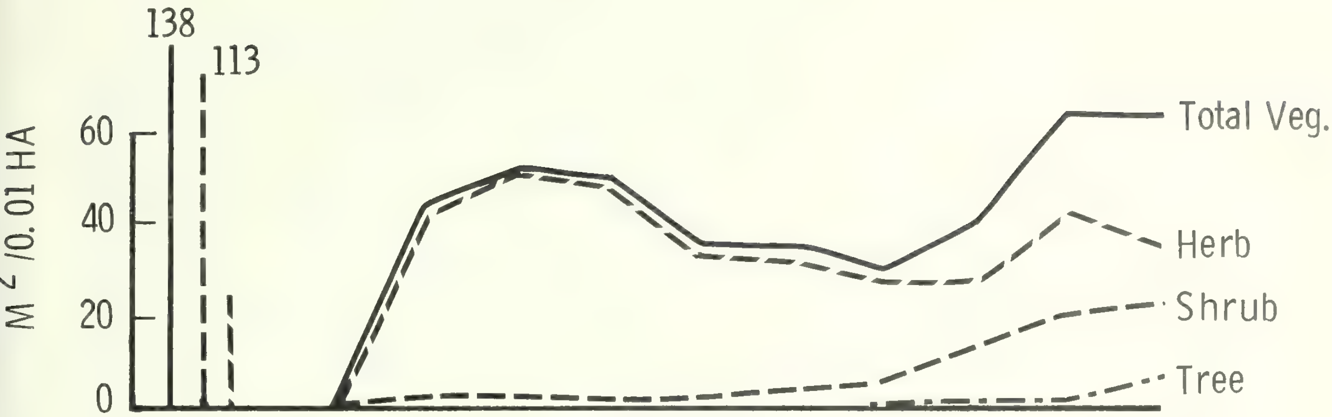


Figure 4-1. Vegetative cover.

Figure 4-2. Vegetative volume.

Table 4-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 4-3.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Acer glabrum	5	-	-	-	-	-	-	-	-	-
Alnus sinuata	7	-	-	-	-	-	-	-	-	-
Lonicera utahensis	-	-	-	-	-	-	-	1	2	2
Menziesia ferruginea	5	-	-	-	-	-	-	-	-	-
Pachistima myrsinites	1	-	-	-	-	-	-	-	1	2
Ribes viscosissimum	-	-	-	-	-	-	-	2	-	<1
Rubus parviflorus	-	-	-	-	-	-	-	1	2	2
Salix scouleriana	-	-	-	-	<1	<1	1	4	6	7
Sorbus scopulina	6	-	-	-	-	-	-	-	-	-
Symphoricarpos albus	-	-	-	-	-	-	-	-	-	<1
Taxus brevifolia	63	-	-	-	-	-	-	-	-	-
Vaccinium globulare	26	1	-	2	2	2	3	7	10	10
Total shrubs	113	1	-	2	2	3	5	14	21	23

Table 4-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 4-4.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Anaphalis margaritaceae	-	-	-	-	-	-	-	2	5	5
Antennaria racemosa	-	-	-	-	-	-	-	1	-	2
Arnica latifolia	12	2	3	5	4	1	-	1	1	1
Cirsium vulgare	-	-	-	-	-	-	-	2	2	1
Clintonia uniflora	1	-	-	1	1	1	1	1	1	1
Epilobium angustifolium	-	41	47	42	27	30	17	17	27	21
Erigeron acris	-	-	-	-	-	-	1	-	-	1
Gnaphalium viscosum	-	-	-	-	-	-	1	-	-	-
Hieracium albiflorum	-	-	-	-	-	-	-	1	-	2
Linnaea borealis	-	-	-	-	-	-	1	-	1	1
Thalictrum occidentale	1	-	-	-	-	-	-	-	-	-
Viola orbiculata	2	-	-	-	-	-	-	-	-	-
Misc. herbs	10	-	1	1	2	1	6	2	6	3
Total herbs	25	42	52	49	33	32	27	27	43	37

Figure 4-3. Shrub cover.

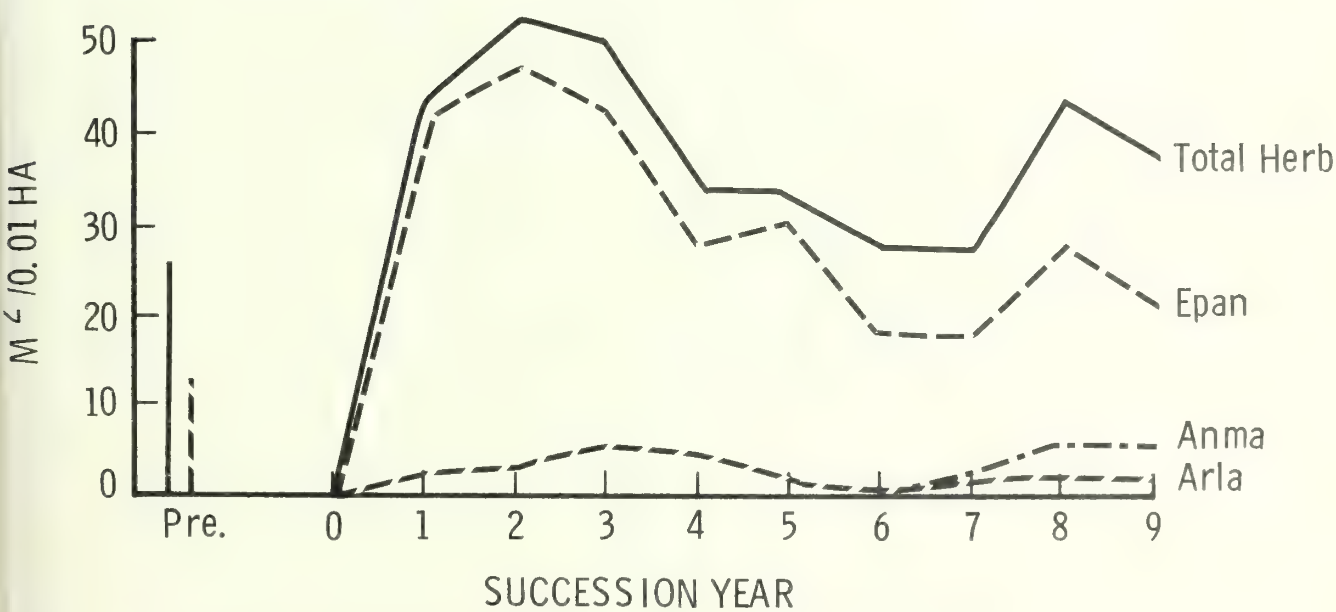


Figure 4-4. Herb cover.

MC: E-6 (A-11)

Table 4-5.--Volume development of shrub component (m^3/0.01 ha), fig. 4-5.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Acer glabrum	16.2	-	-	-	-	-	-	-	-	-
Alnus sinuata	22.7	-	-	-	-	-	-	-	-	-
Lonicera utahensis	-	-	-	-	-	-	-	0.4	1.0	1.5
Menziesia ferruginea	7.3	-	-	-	-	-	-	-	-	-
Pachistima myrsinites	.1	-	-	-	-	-	-	-	.7	1.0
Ribes viscosissimum	-	-	-	-	-	-	-	.8	-	.1
Rubus parviflorus	-	-	-	-	-	-	-	.3	.6	.2
Salix scouleriana	-	-	-	-	0.1	0.1	0.9	3.0	6.8	8.0
Sorbus scopulina	19.5	-	-		-	-	-	-	-	-
Symphoricarpos albus	-	-	-	-	-	-	-	-	-	<.1
Taxus brevifolia	136.6	-	-	-	-	-	-	-	-	-
Vaccinium globulare	15.8	0.1	-	0.3	.3	.6	.8	1.4	3.3	2.5
Total shrubs	218.2	.1	-	.3	.4	.8	1.6	5.9	12.4	13.4

Table 4-6.--Volume development of herb component (m^3/0.01 ha), fig. 4-6.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Anaphalis margaritaceae	-	-	-	-	-	-	-	0.4	1.8	1.7
Antennaria racemosa	-	-	-	-	-	-	-	<.1	-	.7
Arnica latifolia	1.7	0.1	0.7	0.5	0.2	0.1	-	.2	.2	.1
Cirsium vulgare	-	-	-	-	-	-	-	.2	.6	.4
Clintonia uniflora	<.1	-	-	<.1	<.1	<.1	0.1	.1	<.1	<.1
Epilobium angustifolium	-	7.2	26.1	27.7	14.0	16.1	7.3	7.4	14.2	11.2
Erigeron acris	-	-	-	-	-	-	.4	-	-	<.1
Gnaphalium viscosum	-	-	-	-	-	-	.2	-	-	-
Hieracium albiflorum	-	-	-	-	-	-	-	.1	-	.2
Linnaea borealis	-	-	-	-	-	-	<.1	-	<.1	<.1
Thalictrum occidentale	.2	-	-	-	-	-	-	-	-	-
Viola orbiculata	.1	-	-	-	-	-	-	-	-	-
Misc. herbs	1.2	-	.1	.1	.2	.2	.8	.7	.8	.5
Total herbs	3.1	7.3	26.9	28.4	14.5	16.4	8.8	9.1	17.6	14.8

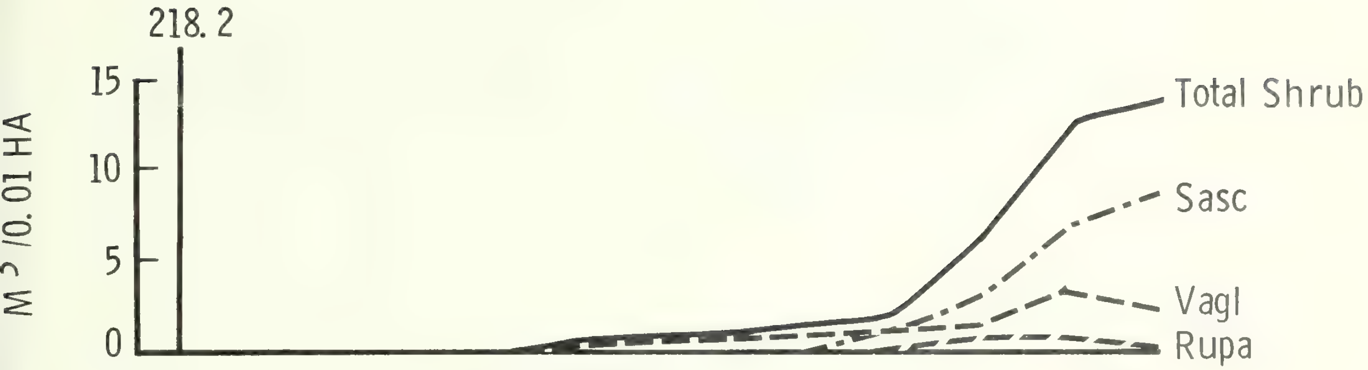


Figure 4-5. Shrub volume.

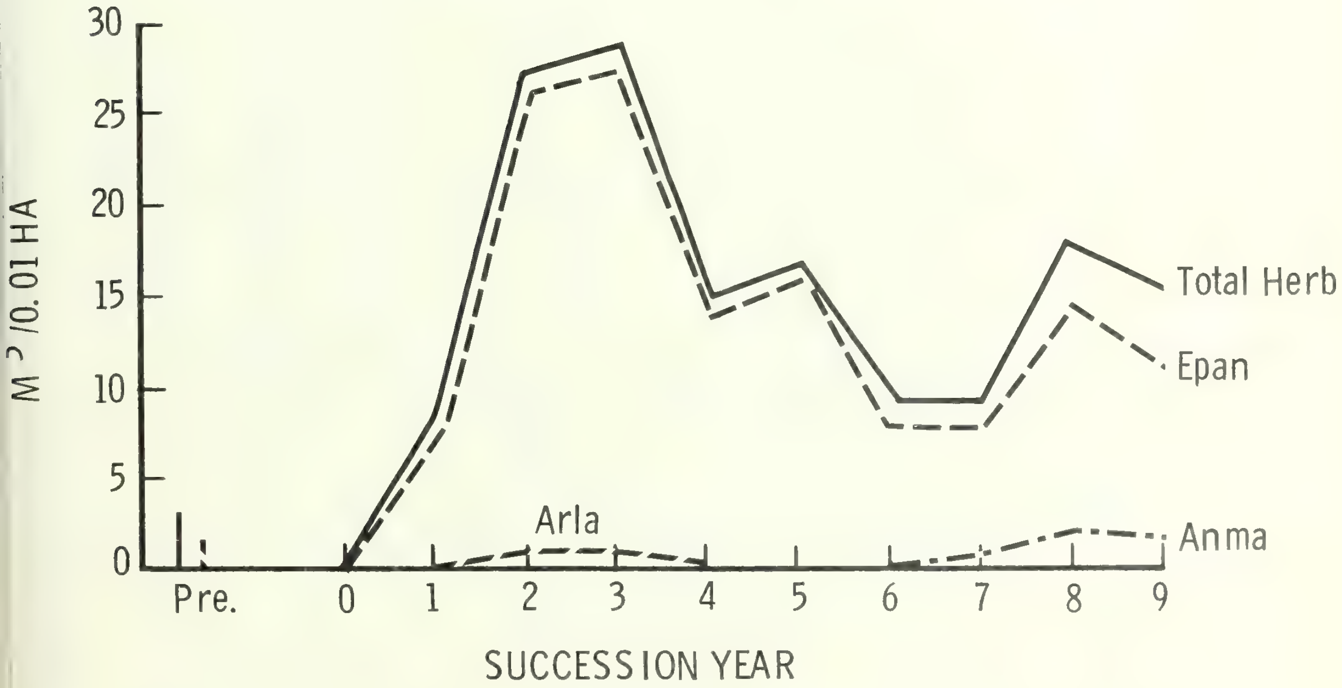


Figure 4-6. Herb volume.

MILLER CREEK: East-8 (1802-13 Area 21-1)

Site location and description: NW¼NW¼ Sec. 16, T32N R24W MPM.
Elevation: 4,700 ft; Exposure: Southeast (Az. 126°); Slope: 10%
Habitat type: Abies lasiocarpa/Clintonia uniflora, Menziesia ferruginea Phase
Predisturbance forest stand: Pien 60%, Abla 22%, Pico 9%, Psme 6%, Laoc 3% (Stand basal area 3,568 cm^2/0.01 ha)
Disturbance treatment: Logged November 1967; Slashed December 1967; Broadcast-burned: October 1, 1970 (Succession year 1:1971); Fire intensity: 881 g water loss; Duff moisture: Upper --%, Lower --%; Postfire duff depth: 6.6 cm (69% of preburn depth)

Table 5-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 5-1.

Life-form component	Succession year						
	Pre	1	2	3	4	5	6
Tree	-	-	-	-	-	-	1
Shrub	98	2	3	11	6	12	12
Herb	55	57	62	41	67	61	60
Total veg.	153	59	66	52	72	73	73
Exposed ground surface:							
Bare ground	-	7	5	4	4	3	2
Rock	-	-	-	1	-	-	-
Litter	18	32	26	35	17	18	25
Moss	2	2	3	10	8	10	5

Table 5-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 5-2.

Life-form component	Succession year						
	Pre	1	2	3	4	5	6
Tree	-	-	-	-	-	-	0.5
Shrub	142.2	0.3	0.8	3.6	1.7	5.2	5.4
Herb	9.7	17.5	22.9	16.7	20.5	18.2	19.5
Total veg.	151.9	17.9	23.6	20.3	22.2	23.4	25.4

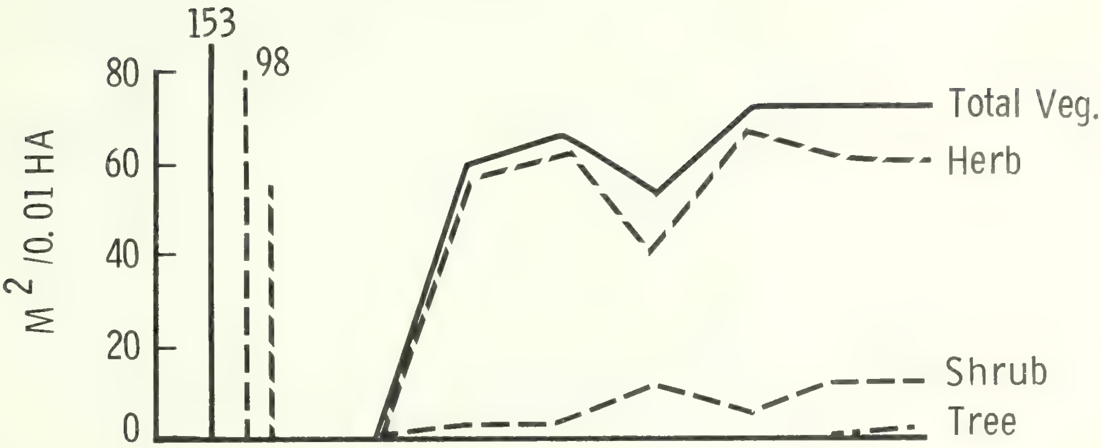


Figure 5-1. Vegetative cover.

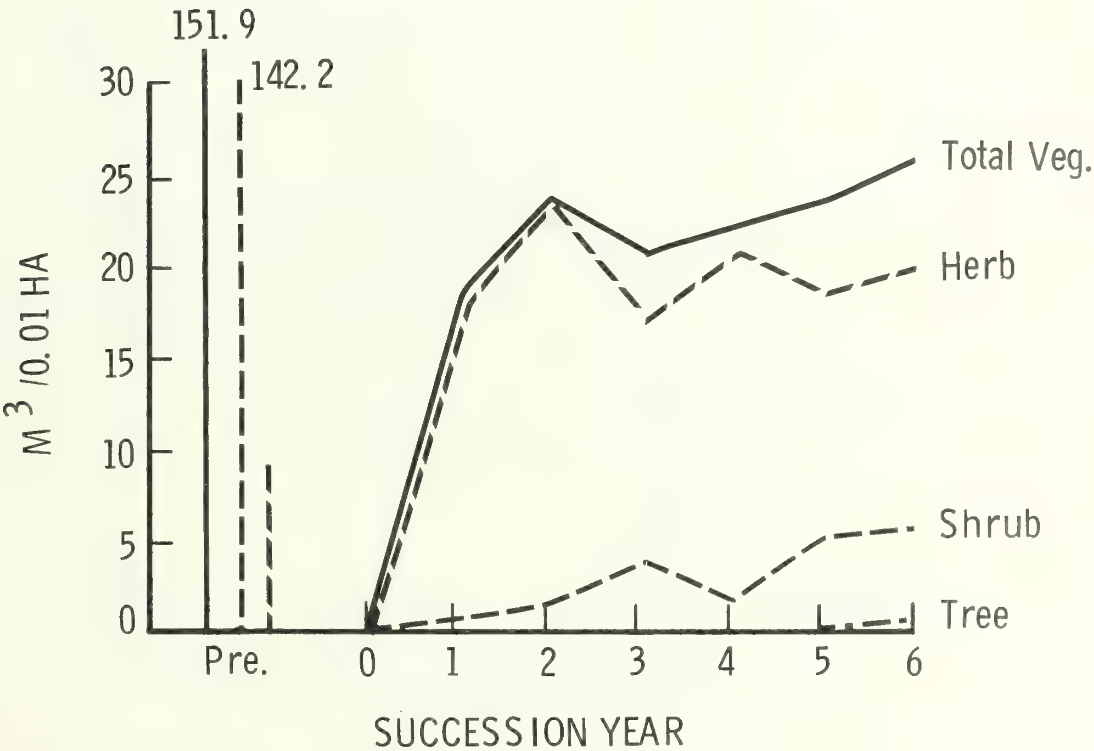


Figure 5-2. Vegetative volume.

Table 5-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 5-3.

Species	Succession year						
	Pre	1	2	3	4	5	6
Acer glabrum	<1	-	-	-	-	-	-
Alnus sinuata	5	-	-	-	-	-	-
Amelanchier alnifolia	2	1	-	-	-	2	1
Menziesia ferruginea	17	-	-	-	-	-	-
Pachistima myrsinites	2	-	-	-	-	-	-
Ribes lacustre	1	-	-	-	-	-	-
Rosa gymnocarpa	4	1	2	4	4	8	8
Rubus parviflorus	1	-	1	1	-	1	1
Sorbus scopulina	-	-	-	<1	-	-	-
Spiraea betulifolia	1	-	-	2	2	1	2
Symphoricarpos albus	-	-	-	2	-	-	-
Taxus brevifolia	36	-	-	-	-	-	-
Vaccinium globulare	28	-	-	-	-	-	-
Total shrubs	98	2	3	10	6	12	12

Table 5-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 5-4.

Species	Succession year						
	Pre	1	2	3	4	5	6
Adenocaulon bicolor	-	2	1	-	1	1	-
Arnica latifolia	38	17	23	8	23	19	12
Berberis repens	-	-	-	1	2	2	2
Carex concinnoides	-	-	-	-	-	-	2
Clintonia uniflora	-	-	-	-	-	-	1
Epilobium angustifolium	-	31	28	21	32	26	27
Geranium bicknellii	-	3	-	-	-	-	-
Linnaea borealis	1	-	-	-	-	-	-
Thalictrum occidentale	-	2	3	4	2	4	3
Xerophyllum tenax	10	1	2	5	5	6	7
Misc. herbs	6	2	4	2	1	2	5
Total herbs	55	57	62	41	67	61	60

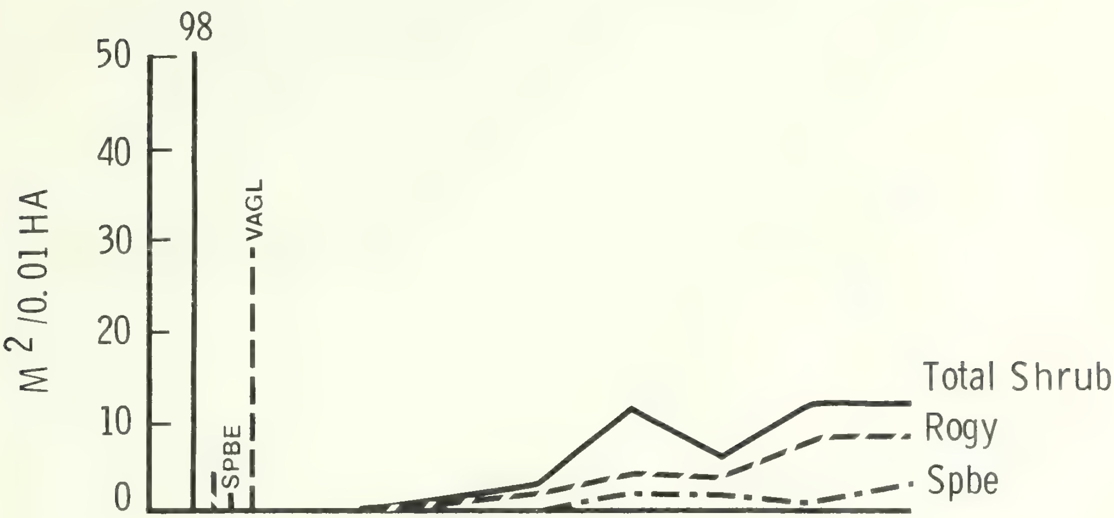


Figure 5-3. Shrub cover.

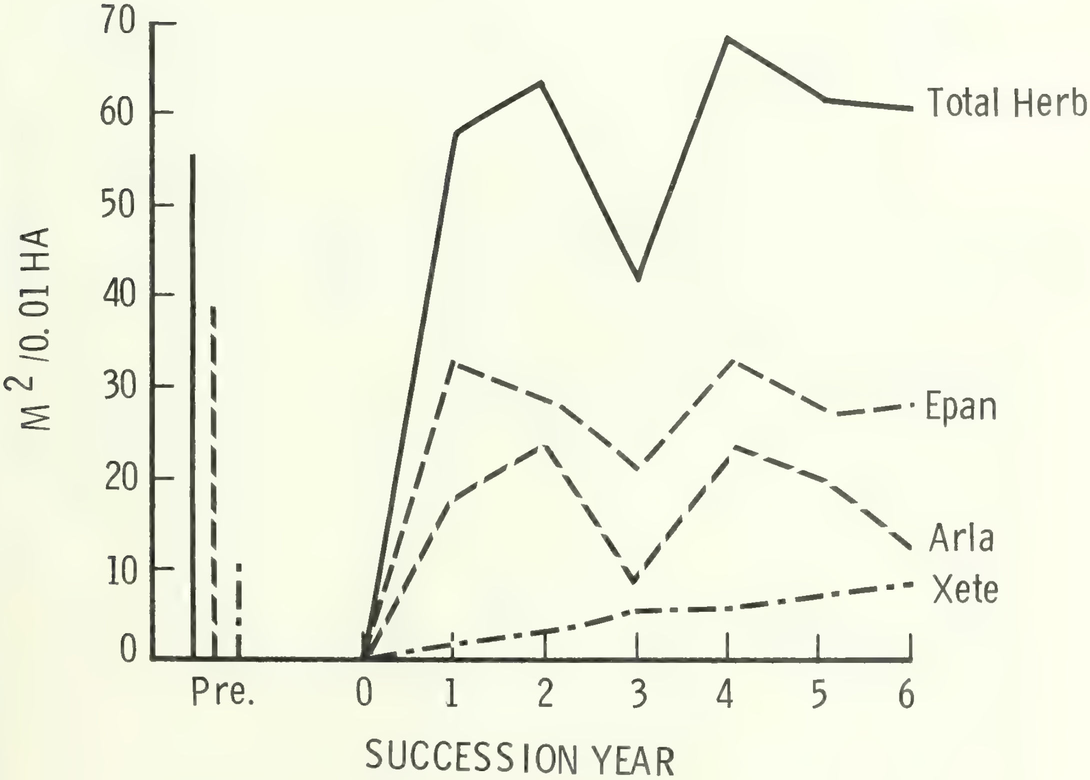


Figure 5-4. Herb cover.

Table 5-5.--Volume development of shrub component (m^3/0.01 ha), fig. 5-5.

Species	Succession year						
	Pre	1	2	3	4	5	6
Acer glabrum	1.4	-	-	-	-	-	-
Alnus sinuata	14.2	-	-	-	-	-	-
Amelanchier alnifolia	3.3	0.2	-	-	-	1.2	0.2
Menziesia ferruginea	24.2	-	-	-	-	-	-
Pachistima myrsinites	.6	-	-	-	-	-	-
Ribes lacustre	.7	-	-	-	-	-	-
Rosa gymnocarpa	1.5	.1	0.5	1.2	1.2	3.6	4.4
Rubus parviflorus	.3	-	.2	.1	-	.2	.1
Sorbus scopulina	-	-	-	.1	-	-	-
Spiraea betulifolia	.4	-	-	.6	.5	.2	.7
Symphoricarpos albus	-	-	-	1.6	-	-	-
Taxus brevifolia	80.9	-	-	-	-	-	-
Vaccinium globulare	14.9	-	-	-	-	-	-
Total shrubs	142.2	.3	.8	3.6	1.7	5.2	5.4

Table 5-6.--Volume development of herb component (m^3/0.01 ha), fig. 5-6.

Species	Succession year						
	Pre	1	2	3	4	5	6
Adenocaulon bicolor	-	0.4	0.2	-	0.2	0.1	-
Arnica latifolia	6.7	1.7	5.5	0.9	2.8	2.2	1.1
Berberis repens	-	-	-	<.1	.3	.2	.2
Carex concinnoides	-	-	-	-	-	-	.1
Clintonia uniflora	-	-	-	-	-	-	.1
Epilobium angustifolium	-	14.5	14.5	13.7	15.8	12.6	13.9
Geranium bicknellii	-	.2	-	-	-	-	-
Linnaea borealis	<.1	-	-	-	-	-	-
Thalictrum occidentale	-	.4	1.4	1.0	.3	.9	1.4
Xerophyllum tenax	2.4	.1	.5	1.0	.9	1.9	1.5
Misc. herbs	.5	.3	.8	.2	.1	.3	1.2
Total herbs	9.7	17.5	22.9	16.7	20.5	18.2	19.5

Figure 5-5. Shrub volume.

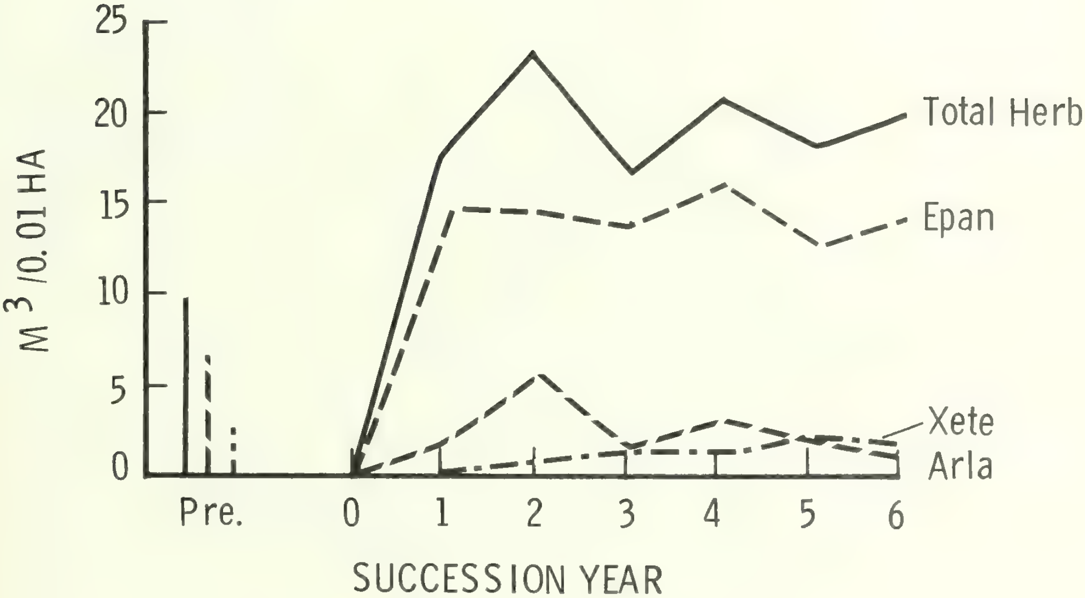


Figure 5-6. Herb volume.

MILLER CREEK: East-9 (1802-13 Area 21-3)

Site location and description: NW¼NW¼ Sec. 16, T32N R24W MPM.
Elevation: 4,700 ft; Exposure: East (Az. 106°); Slope: 15%
Habitat type: Abies lasiocarpa/Clintonia uniflora, Xerophyllum tenax Phase
Predisturbance forest stand: Laoc 53%, Abla 22%, Psme 14%, Pico 11% (Stand basal area 6,747 cm^2/0.01 ha)
Disturbance treatment: Logged November 1967; Slashed December 1967; Broadcast-burned: October 1, 1970 (Succession year 1:1971)
Fire intensity: 834 g water loss; Duff moisture: Upper --%, Lower --%; Postfire duff depth: 4.7 cm (62% of preburn depth)

Table 6-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 6-1.

Life-form component	Succession year						
	Pre	1	2	3	4	5	6
Tree	1	-	-	-	-	-	-
Shrub	36	2	7	3	11	28	22
Herb	48	34	47	52	47	42	42
Total veg.	85	37	54	56	57	71	64
Exposed ground surface:							
Bare ground	-	13	2	5	2	1	2
Rock	-	1	-	-	1	1	1
Litter	40	33	37	35	29	22	29
Moss	2	16	8	5	12	14	8

Table 6-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 6-2.

Life-form component	Succession year						
	Pre	1	2	3	4	5	6
Tree	0.3	-	-	-	-	-	-
Shrub	99.8	0.6	1.9	0.8	3.4	10.4	12.8
Herb	10.1	7.3	15.3	18.4	12.7	13.3	14.0
Total veg.	110.2	8.0	17.2	19.2	16.1	23.8	26.8

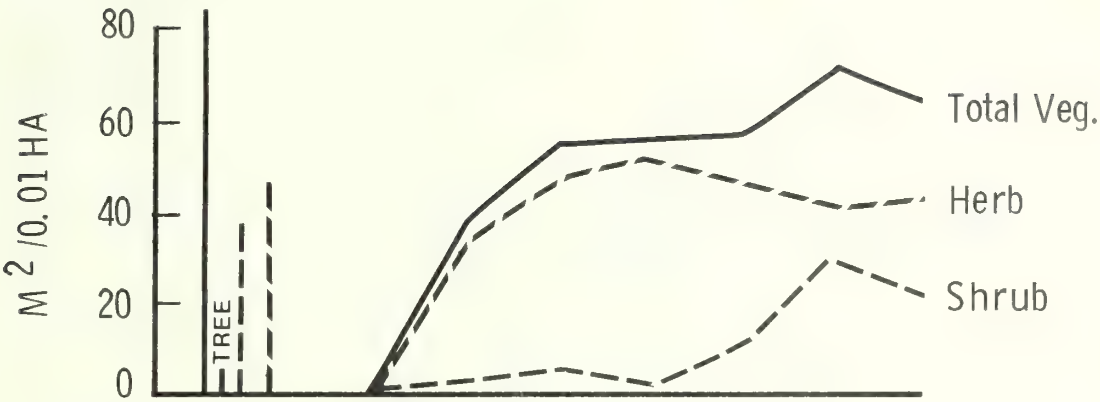


Figure 6-1. Vegetative cover.

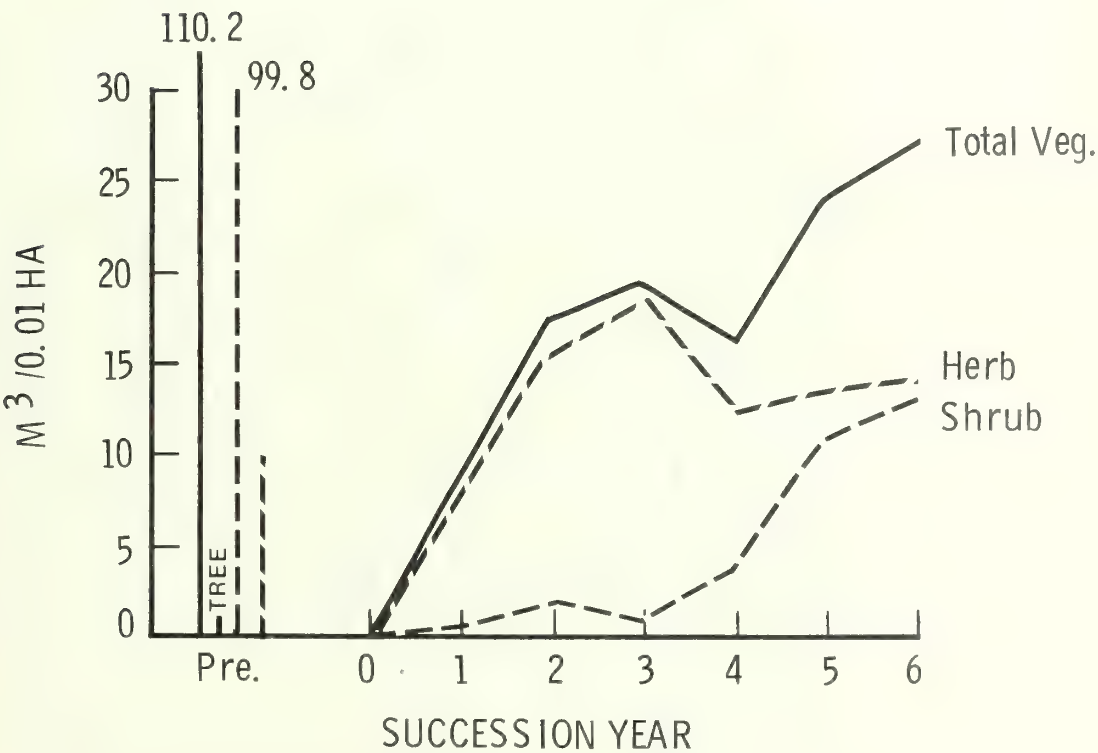


Figure 6-2. Vegetative volume.

Table 6-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 6-3.

Species	Succession year						
	Pre	1	2	3	4	5	6
Acer glabrum	16	-	-	-	-	-	3
Alnus sinuata	1	-	-	-	-	-	-
Rosa gymnocarpa	6	-	2	3	6	12	8
Rubus parviflorus	-	-	2	-	2	2	2
Salix scouleriana	-	-	-	-	-	1	-
Sorbus scopulina	<1	-	-	-	-	-	<1
Spiraea betulifolia	1	1	1	-	-	6	5
Symphoricarpos albus	2	2	2	-	3	8	4
Taxus brevifolia	1	-	-	-	-	-	-
Vaccinium globulare	8	-	-	-	-	1	-
Total shrubs	36	2	7	3	11	28	22

Table 6-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 6-4.

Species	Succession year						
	Pre	1	2	3	4	5	6
Adenocaulon bicolor	-	-	-	1	-	-	-
Arnica latifolia	24	9	13	20	12	2	2
Aster conspicuus	-	-	-	-	-	1	1
Berberis repens	1	-	1	1	-	1	-
Carex concinnoides	-	-	-	-	2	4	4
Carex rossii	-	-	-	-	-	-	1
Chimaphila umbellata	1	-	-	-	-	-	-
Cirsium arvense	-	-	-	-	-	2	2
Clintonia uniflora	2	-	-	-	-	-	-
Epilobium angustifolium	-	17	22	23	19	17	17
Epilobium watsonii	-	-	1	-	-	-	-
Geranium bicknellii	-	2	-	-	-	-	-
Gnaphalium viscosum	-	-	-	-	-	1	1
Thalictrum occidentale	4	1	5	4	3	3	2
Xerophyllum tenax	10	2	2	3	6	8	8
Misc. herbs	7	3	2	-	4	3	4
Total herbs	48	34	47	52	47	42	42

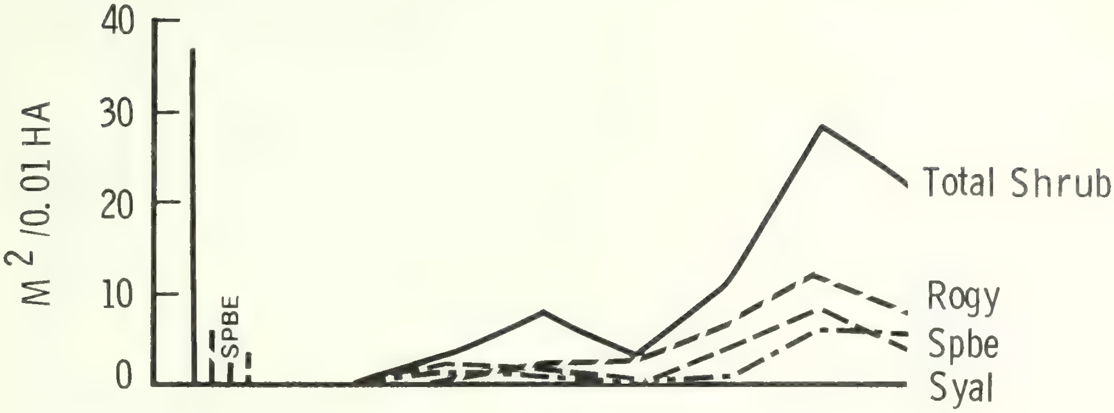


Figure 6-3. Shrub cover.

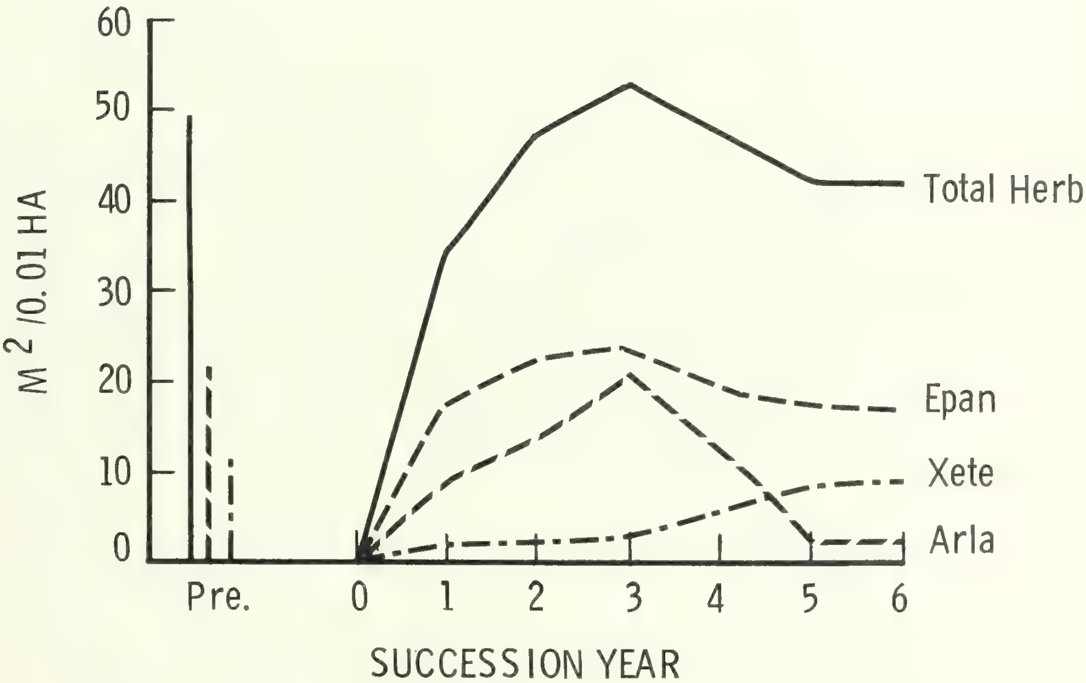


Figure 6-4. Herb cover.

MC: E-9 (A-21-3)

Table 6-5.--Volume development of shrub component (m^3/0.01 ha), fig. 6-5.

Species	Succession year						
	Pre	1	2	3	4	5	6
Acer glabrum	89.1	-	-	-	-	-	7.0
Alnus sinuata	2.0	-	-	-	-	-	-
Rosa gymnocarpa	3.6	-	0.7	0.8	2.1	4.6	2.3
Rubus parviflorus	-	-	.3	-	.3	.2	.3
Salix scouleriana	-	-	-	-	-	.6	-
Sorbus scopulina	.2	-	-	-	-	-	.2
Spiraea betulifolia	.2	0.1	.2	-	-	1.4	1.4
Symphoricarpos albus	.9	.5	.7	-	1.1	3.5	1.5
Taxus brevifolia	.4	-	-	-	-	-	-
Vaccinium globulare	3.4	-	-	-	-	.1	-
Total shrubs	99.8	.6	1.9	.8	3.4	10.4	12.8

Table 6-6.--Volume development of herb component (m^3/0.01 ha), fig. 6-6.

Species	Succession year						
	Pre	1	2	3	4	5	6
Adenocaulon bicolor	-	-	-	0.1	-	-	-
Arnica latifolia	4.9	0.9	2.9	2.2	1.3	0.2	0.1
Aster conspicuus	-	-	-	-	-	.3	2
Berberis repens	.2	-	<.1	.1	-	<.1	-
Carex concinnoides	-	-	-	-	.2	.4	.4
Carex rossii	-	-	-	-	-	-	.1
Chimaphila umbellata	.1	-	-	-	-	-	-
Cirsium arvense	-	-	-	-	-	1.0	.7
Clintonia uniflora	.1	-	-	-	-	-	-
Epilobium angustifolium	-	5.7	10.1	14.2	8.8	8.0	9.2
Epilobium watsonii	-	-	<.1	-	-	-	-
Geranium bicknellii	-	.1	-	-	-	-	-
Gnaphalium viscosum	-	-	-	-	-	.2	.2
Thalictrum occidentale	1.5	.1	1.3	1.1	.8	1.2	.5
Xerophyllum tenax	2.7	.2	.3	.7	.9	1.4	1.8
Misc. herbs	.5	.4	.5	-	.7	.4	.8
Total herbs	10.1	7.3	15.3	18.4	12.7	13.3	14.0

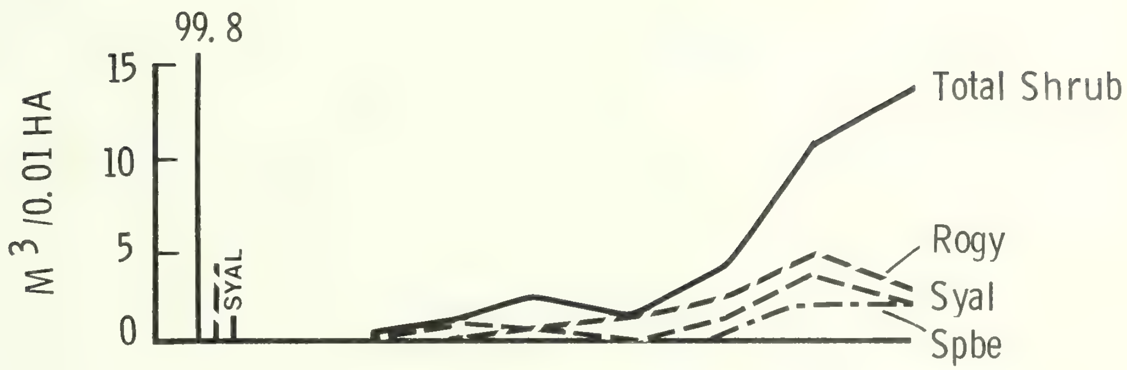


Figure 6-5. Shrub volume.

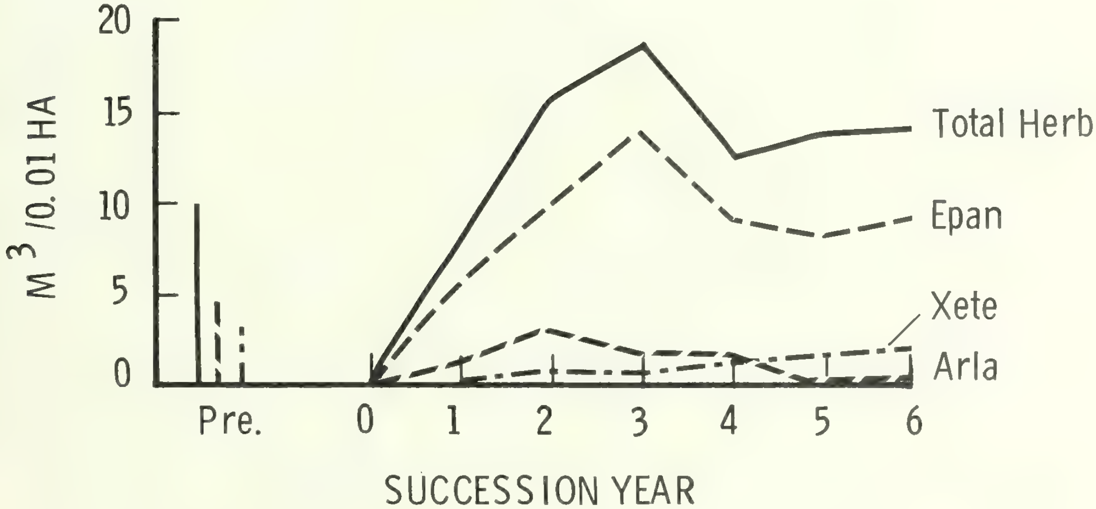


Figure 6-6. Herb volume.

MILLER CREEK: South-1 (1802-13 Area 12)

Site location and description: NE¼SE¼ Sec. 19, T32N R24W MPM.
Elevation 4,900 ft; Exposure: Southwest (Az. 206°) Slope: 10%
Habitat type: Abies lasiocarpa/Clintonia uniflora, Xerophyllum tenax Phase
Predisturbance forest stand: Pien 31%, Laoc 29%, Psme 27%, Pico 7%, Abla 6% (Stand basal area: 5,324 cm^2/0.01 ha)
Disturbance treatment: Logged June 1967; Slashed June 1967;
Broadcast burned: May 18, 1968 (Succession year 1:1968);
Fire intensity: 286 g water loss; Duff moisture: Upper 41%, Lower 135%; Postfire duff depth: 4.3 cm (84% of preburn depth)

Table 7-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 7-1.

Life-form component	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Tree	-	-	-	-	-	-	-	-	-	-
Shrub	33	1	9	14	12	18	17	23	36	30
Herb	44	10	25	61	56	45	47	49	50	43
Total veg.	77	11	34	75	67	63	63	72	86	73
Exposed ground surface:										
Bare ground	-	11	14	8	5	4	2	1	2	2
Rock	-	-	-	-	-	-	1	-	1	-
Litter	29	78	52	25	27	34	35	26	20	28
Moss	8	-	-	-	3	6	4	9	7	8

Table 7-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 7-2.

Life-form component	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Tree	-	-	-	-	-	-	-	-	-	-
Shrub	13.3	0.1	3.1	6.2	4.6	9.9	9.9	9.8	21.8	19.6
Herb	5.6	.6	6.8	21.0	17.6	12.9	16.3	16.2	20.9	15.6
Total veg.	18.9	.7	9.9	27.2	22.2	22.8	26.2	26.0	42.7	35.2

MC: S-1 (A-12)

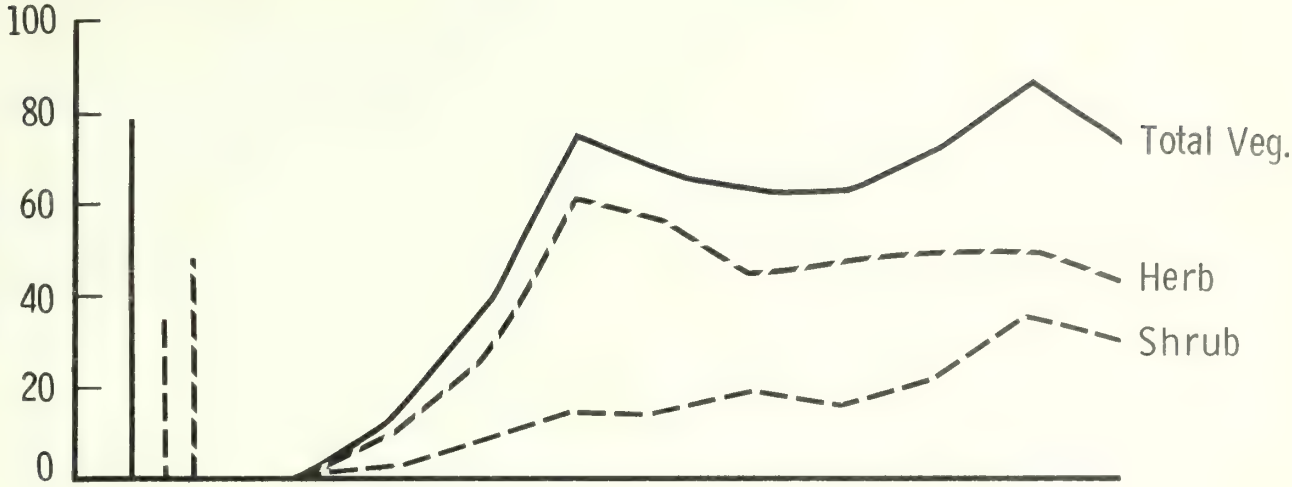


Figure 7-1. Vegetative cover.

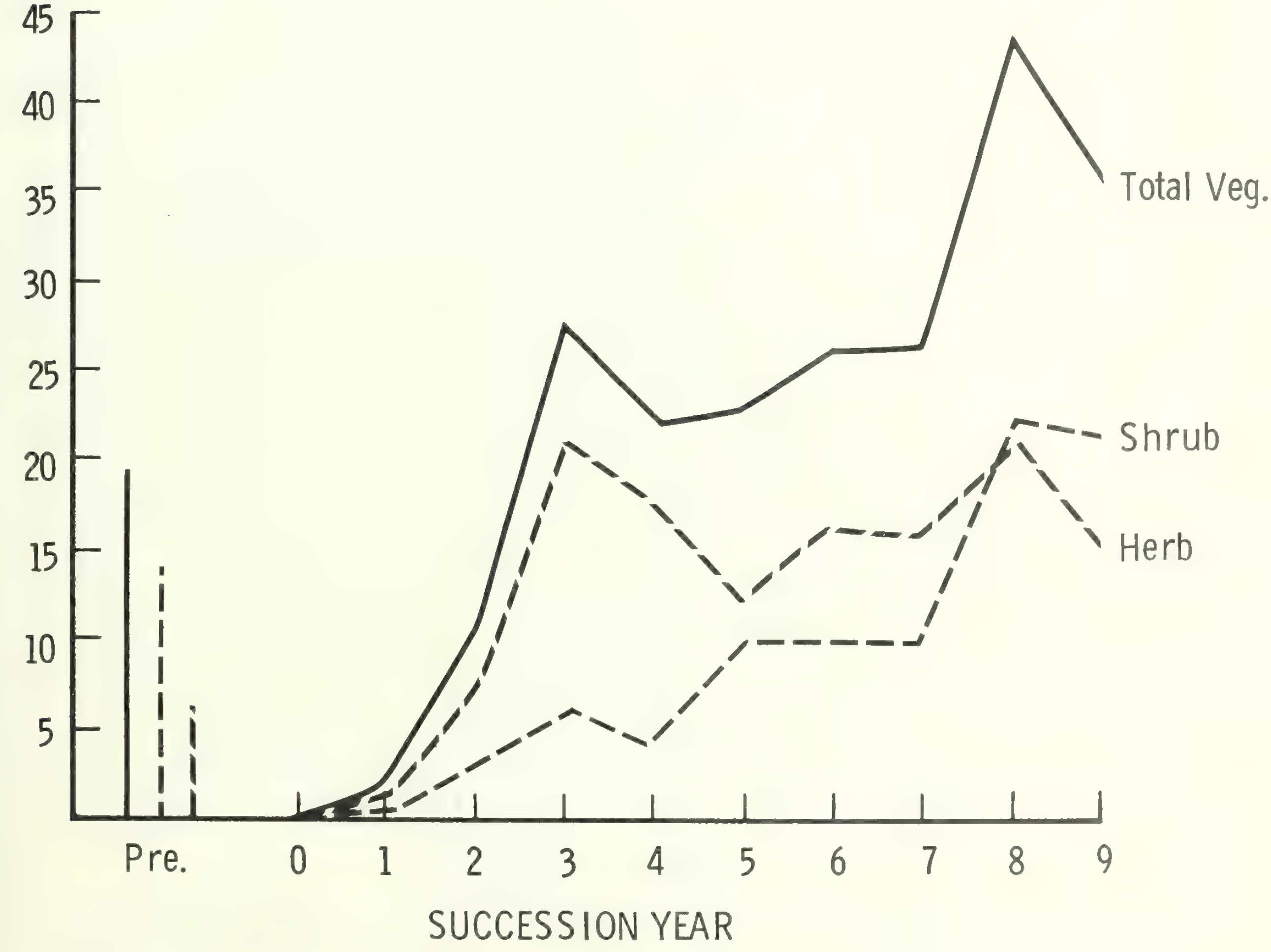


Figure 7-2. Vegetative volume.

MC: S-1 (A-12)

Table 7-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 7-3.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Pachistima myrsinites	1	-	-	-	-	-	-	1	3	3
Ribes viscosissimum	-	-	-	4	3	5	3	5	6	7
Rosa gymnocarpa	<1	-	<1	-	-	-	-	-	-	-
Rubus parviflorus	1	1	5	3	3	2	2	2	4	3
Salix scouleriana	-	-	1	2	2	5	4	3	6	4
Spiraea betulifolia	1	-	4	4	2	3	5	6	6	6
Taxus brevifolia	1	-	-	-	-	-	-	-	-	-
Vaccinium globulare	29	-	-	2	2	3	2	6	11	8
Total shrubs	33	1	9	14	12	18	17	23	36	30

Table 7-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 7-4.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Anaphalis margaritaceae	-	-	-	-	-	-	2	2	2	1
Arnica latifolia	14	-	6	12	10	11	5	3	-	-
Berberis repens	<1	-	-	-	-	-	-	-	1	1
Carex concinnoides	-	-	-	-	-	-	-	-	1	2
Chimaphila umbellata	2	-	-	-	-	-	-	-	-	-
Cirsium vulgare	-	-	2	2	-	-	-	1	2	1
Deschampsia elongata	-	-	-	-	-	-	-	1	-	-
Epilobium angustifolium	-	-	6	18	22	17	20	23	27	17
Epilobium paniculatum	-	-	1	13	8	-	-	-	-	-
Epilobium watsonii	-	-	1	-	-	-	-	-	-	-
Gnaphalium viscosum	-	-	-	-	-	1	-	-	-	-
Linnaea borealis	2	-	-	1	2	1	1	1	1	1
Viola orbiculata	1	-	-	1	-	-	-	-	-	-
Xerophyllum tenax	13	3	7	10	11	12	14	13	15	14
Misc. herbs	12	-	2	3	2	4	5	5	2	6
Total shrubs	44	10	25	61	56	45	47	49	50	43

Figure 7-3. Shrub cover.

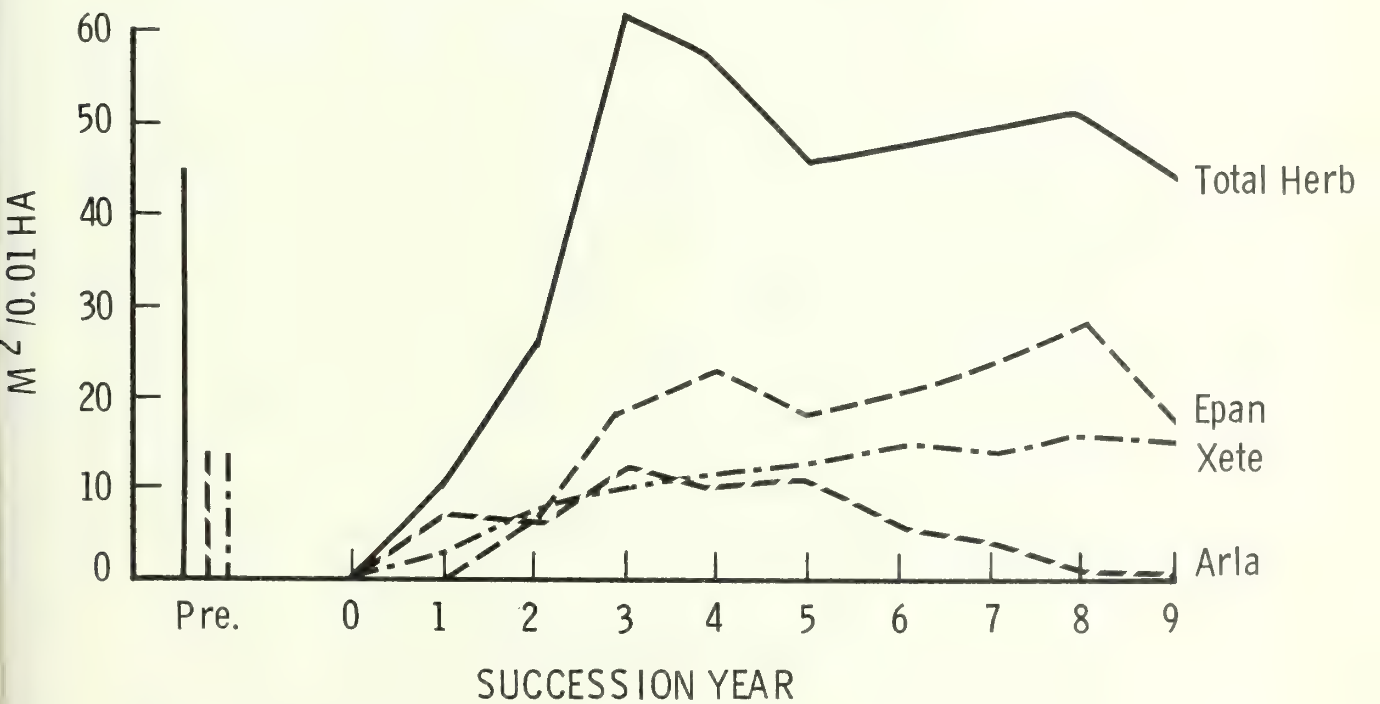


Figure 7-4. Herb cover.

Table 7-5.--Volume development of shrub component (m^3/0.01 ha), fig. 7-5.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Pachistima myrsinites	0.1	-	-	-	-	-	-	0.2	0.7	0.5
Ribes viscosissimum	-	-	-	1.5	1.3	2.5	1.5	2.2	5.5	5.4
Rosa gymnocarpa	.3	-	0.3	-	-	-	-	-	-	-
Rubus parviflorus	.1	0.1	1.7	1.5	.7	.3	.3	.5	.9	.5
Salix scouleriana	-	-	.4	1.3	2.0	5.3	5.9	3.9	9.5	9.2
Spiraea betulifolia	.4	-	1.1	1.6	.5	1.2	1.8	2.0	2.6	2.3
Taxus brevifolia	.4	-	-	-	-	-	-	-	-	-
Vaccinium globulare	12.0	-	-	.2	.2	.5	.4	1.0	2.7	1.6
Total shrubs	13.3	.1	3.1	6.2	4.6	9.9	9.9	9.8	21.8	19.6

Table 7-6.--Volume development of herb component (m^3/0.01 ha), fig. 7-6.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Anaphalis margaritaceae	-	-	-	-	-	-	0.6	0.5	0.4	0.2
Arnica latifolia	1.8	0.3	1.0	2.8	1.4	1.2	.5	.3	-	-
Berberis repens	.1	-	-	-	-	-	-	-	<.1	.1
Carex concinnoides	-	-	-	-	-	-	-	-	.1	.4
Chimaphila umbellata	.2	-	-	-	-	-	-	-	-	-
Cirsium vulgare	-	-	1.4	1.4	-	-	-	.1	.2	<.1
Deschampsia elongata	-	-	-	-	-	-	-	.2	-	-
Epilobium angustifolium	-	-	1.5	8.8	12.5	7.8	10.8	11.3	15.4	9.6
Epilobium paniculatum	-	-	.4	4.7	.5	-	-	-	-	-
Epilobium watsonii	-	-	.3	-	-	-	-	-	-	-
Gnaphalium viscosum	-	-	-	-	-	.2	-	-	-	-
Linnaea borealis	.1	-	-	<.1	.2	<.1	<.1	<.1	<.1	<.1
Viola orbiculata	<.1	-	-	<.1	-	-	-	-	-	-
Xerophyllum tenax	2.1	.3	1.8	2.6	2.5	3.1	3.8	3.0	4.5	4.2
Misc. herbs	1.2	-	.4	.6	.4	.5	.5	.7	.2	1.0
Total herbs	5.6	.6	6.8	21.0	17.6	12.9	16.3	16.2	20.9	15.6

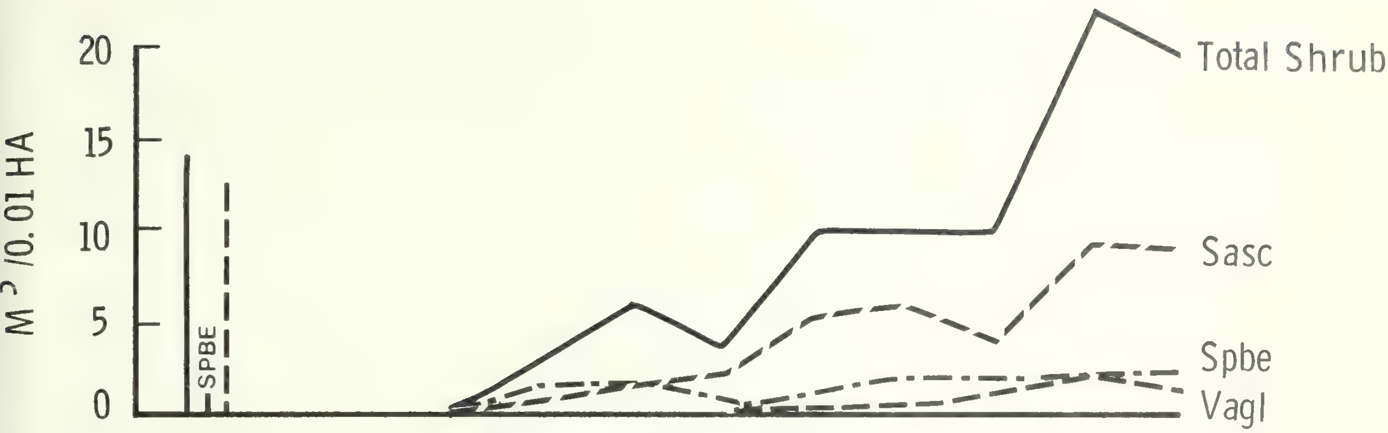


Figure 7-5. Shrub volume.

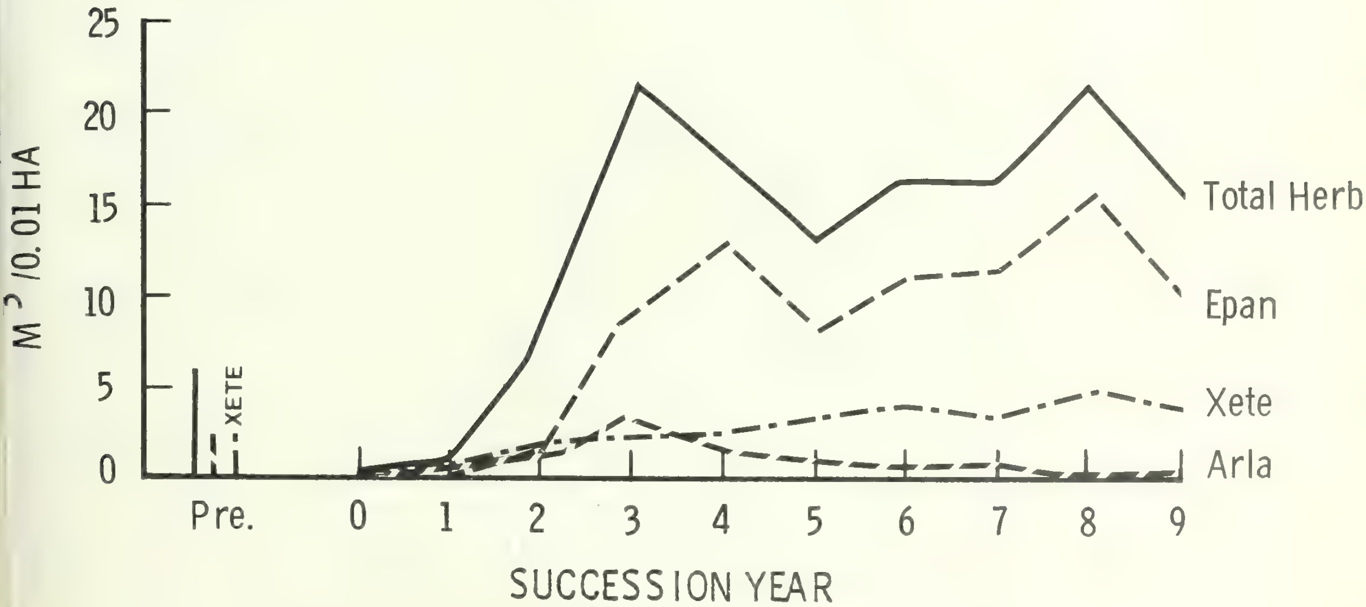


Figure 7-6. Herb volume.

MILLER CREEK: South-2 (1802-13 Area 14-3)

Site location and description: NE¼SE¼ Sec. 19, T32N R24W MPM.
Elevation: 4,900 ft; Exposure: South (Az. 160°); Slope: 25%
Habitat type: Abies lasiocarpa/Clintonia uniflora, Xerophyllum tenax phase
Predisturbance forest stand: Pien 37%, Psme 31%, Laoc 21%, Abla 9%, Pico 3% (Stand basal area: 5,505 cm^2/0.01 ha)
Disturbance treatment: Logged December 1967; Slashed February 1968; Broadcast-burned: May 18, 1968 (Succession year 1:1968); Fire intensity: -- g water loss; Duff moisture: Upper 41%, Lower 135%; Postfire duff depth: -- cm (--% of preburn depth)

Table 8-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 8-1.

Life-form component	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Tree	-	-	-	-	-	-	-	-	-	-
Shrub	54	-	6	10	10	8	14	13	20	12
Herb	35	6	20	46	52	54	49	52	48	59
Total veg.	89	6	26	56	62	62	63	65	69	71
Exposed ground surface:										
Bare ground	-	2	-	2	1	1	-	-	2	-
Rock	-	-	-	-	-	-	-	-	-	-
Litter	38	92	74	42	37	37	42	33	27	29
Moss	17	-	-	-	2	2	-	4	7	2

Table 8-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 8-2.

Life-form component	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Tree	-	-	-	-	-	-	-	-	-	-
Shrub	84.9	-	1.2	2.0	2.5	1.9	5.0	4.2	8.5	5.7
Herb	4.2	0.8	6.3	16.7	16.2	16.9	14.6	14.4	15.9	15.8
Total veg.	89.1	.8	7.4	18.6	18.7	18.8	19.6	18.6	24.4	21.5

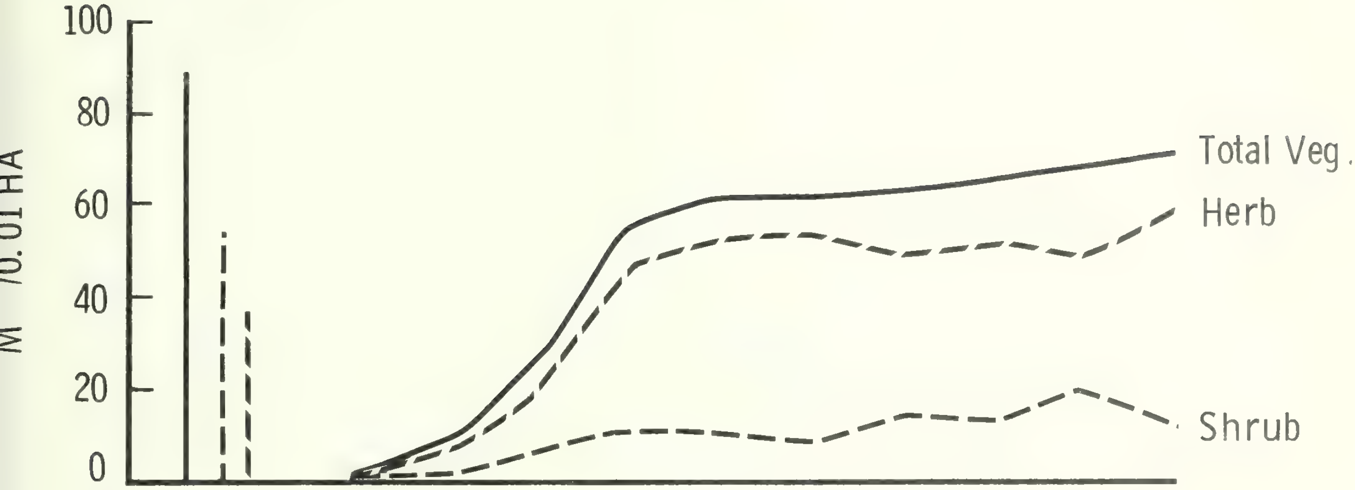


Figure 8-1. Vegetative cover.

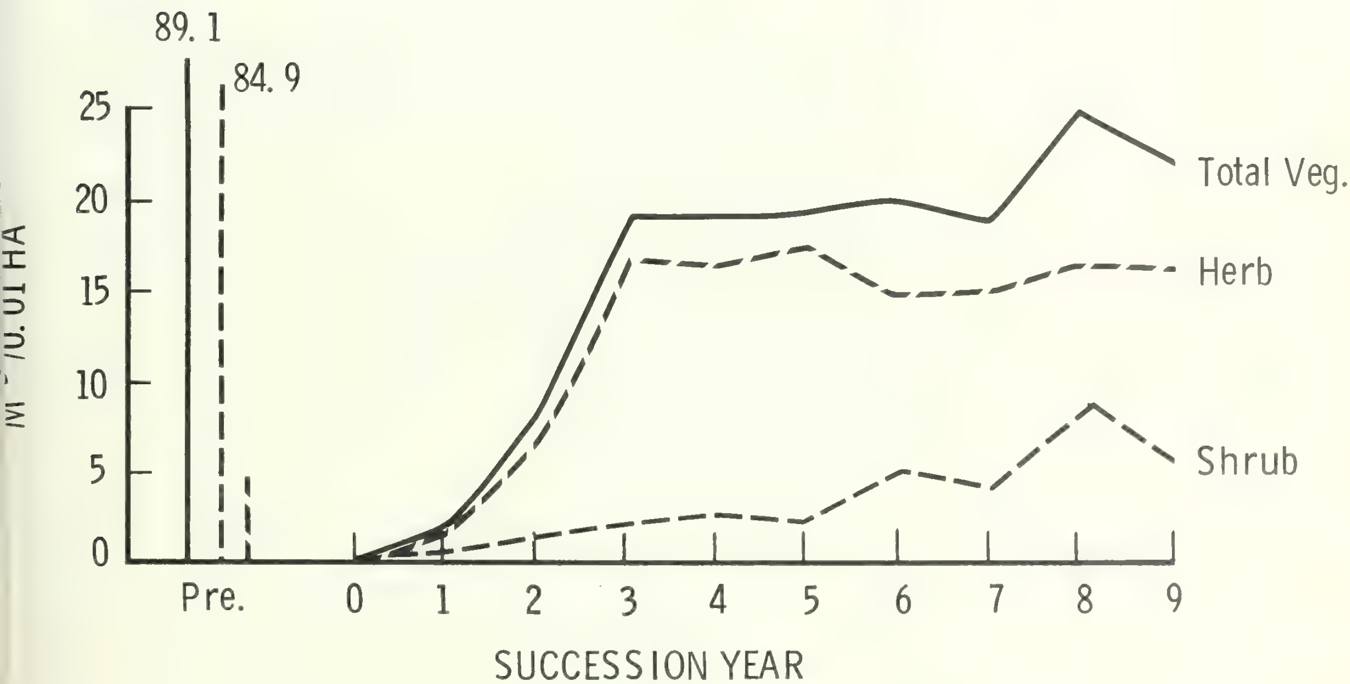


Figure 8-2. Vegetative volume.

MC: S-2 (A-14-3)

Table 8-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 8-3.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Alnus sinuata	-	-	<1	-	-	-	-	-	-	-
Lonicera utahensis	-	-	-	-	-	-	-	-	-	2
Menziesia ferruginea	18	-	-	-	1	1	3	1	2	-
Pachistima myrsinites	1	-	1	2	1	1	1	2	2	1
Ribes lacustre	1	-	-	-	-	-	1	-	-	<1
Ribes viscosissimum	-	-	-	-	-	-	-	-	-	<1
Rosa gymnocarpa	-	-	-	-	-	-	-	-	1	-
Rubus parviflorus	-	-	1	1	2	1	1	3	3	1
Salix scouleriana	-	-	<1	-	-	-	1	<1	2	1
Spiraea betulifolia	2	-	2	5	4	1	4	2	3	2
Taxus brevifolia	22	-	-	-	-	-	-	-	-	-
Vaccinium globulare	11	-	2	2	2	4	3	4	7	5
Vaccinium scoparium	1	-	-	-	-	-	-	-	-	-
Total shrubs	54	-	6	10	10	8	14	13	20	12

Table 8-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 8-4.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Carex concinnoides	-	-	-	-	1	1	1	3	2	2
Chimaphila umbellata	2	-	-	-	-	-	-	-	-	-
Cirsium vulgare	-	-	3	-	-	-	-	-	-	-
Epilobium angustifolium	-	-	2	17	17	19	14	22	18	14
Epilobium paniculatum	-	-	-	2	2	-	-	-	-	-
Linnaea borealis	7	-	3	6	10	12	15	10	12	18
Xerophyllum tenax	17	-	11	18	17	20	16	17	13	22
Misc. herbs	9	6	1	2	3	2	3	-	2	2
Total herbs	35	6	20	46	52	54	49	52	48	59

Figure 8-3. Shrub cover.

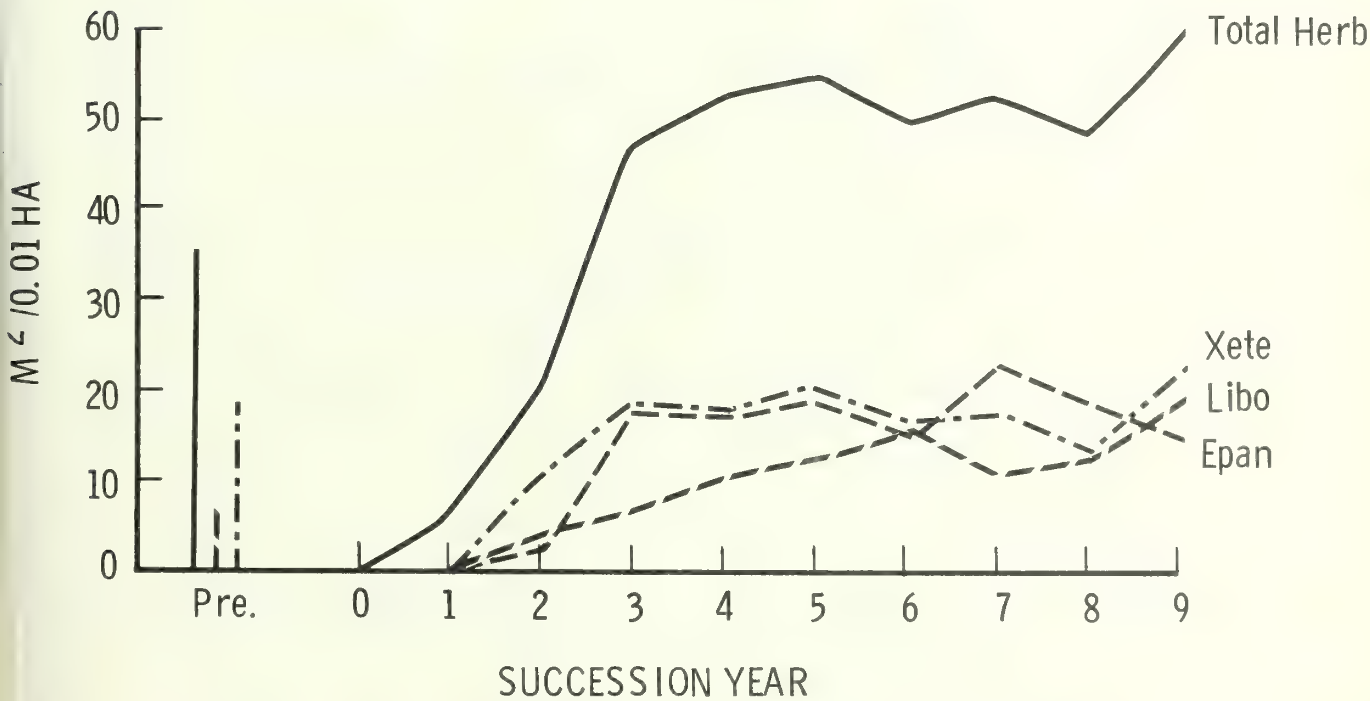


Figure 8-4. Herb cover.

MC: S-2 (A-14-3)

Table 8-5.--Volume development of shrub component (m^3/0.01 ha), fig. 8-5.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Alnus sinuata	-	-	0.1	-	-	-	-	-	-	-
Lonicera utahensis	-	-	-	-	-	-	-	-	-	1.8
Menziesia ferruginea	28.3	-	-	-	0.4	0.6	2.2	1.1	2.6	-
Pachistima myrsinites	.1	-	.1	0.2	.2	.1	.1	.3	.5	.2
Ribes lacustre	.6	-	-	-	-	-	.5	-	-	.1
Ribes viscosissimum	-	-	-	-	-	-	-	-	-	.2
Rosa gymnocarpa	-	-	-	-	-	-	-	-	.3	-
Rubus parviflorus	-	-	.3	.1	.5	.1	.2	.9	.9	.3
Salix scouleriana	-	-	<.1	-	-	-	.5	.4	1.9	1.4
Spiraea betulifolia	.5	-	.4	1.2	1.2	.2	.9	.6	.9	.8
Taxus brevifolia	51.2	-	-	-	-	-	-	-	-	-
Vaccinium globulare	4.2	-	.2	.4	.2	.8	.5	.8	1.4	1.0
Vaccinium scoparium	<.1	-	-	-	-	-	-	-	-	-
Total shrubs	84.9	-	1.2	2.0	2.5	1.9	5.0	4.2	8.5	5.7

Table 8-6.--Volume development of herb component (m^3/0.01 ha), fig. 8-6.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Carex concinnoides	-	-	-	-	<0.1	<0.1	0.1	0.3	0.2	0.2
Chimaphila umbellata	0.2	-	-	-	-	-	-	-	-	-
Cirsium vulgare	-	-	2.5	-	-	-	-	-	-	-
Epilobium angustifolium	-	-	.6	9.0	9.4	11.1	9.0	10.4	12.0	8.4
Epilobium paniculatum	-	-	-	1.5	.2	-	-	-	-	-
Linnaea borealis	.3	-	.2	.3	1.2	.6	.8	.5	.6	.9
Xerophyllum tenax	2.8	-	2.9	5.4	4.7	4.7	4.3	3.2	2.8	5.8
Misc. herbs	.9	0.8	.1	.6	.5	.5	.5	-	.3	.5
Total herbs	4.2	.8	6.3	16.7	16.2	16.9	14.6	14.4	15.9	15.8

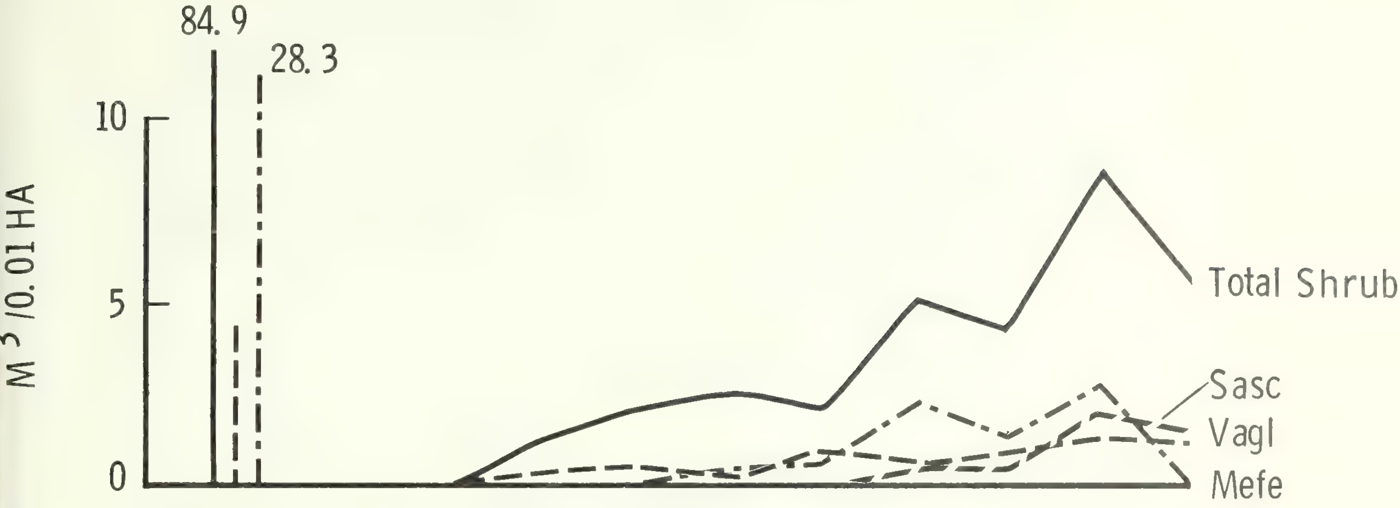


Figure 8-5. Shrub volume.

Figure 8-6. Herb volume.

MILLER CREEK: West-3 (1802-13 Area 20)

Site location and description: NE¼NW¼ Sec. 20, T32N R24W MPM.
Elevation: 4,700 ft; Exposure: West (Az. 255°); Slope: 55%
Habitat type: Abies lasiocarpa/Clintonia uniflora, Aralia nudicaulis Phase
Predisturbance forest stand: Abla 34%, Laoc 26%, Pien 26%, Psme 10%, Pico 4% (Stand basal area: 2,173 cm^2/0.01 ha)
Disturbance treatment: Logged October 1967; Slashed October 1967;
Broadcast-burned: September 30, 1968 (Succession year 1:1969);
Fire intensity: 423 g water loss; Duff moisture: Upper 65%,
Lower 179%; Postfire duff depth: 4.5 cm (89% of preburn depth)

Table 9-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 9-1.

Life-form component	Succession year								
	Pre	1	2	3	4	5	6	7	8
Tree	-	-	-	-	-	-	-	-	-
Shrub	156	7	21	23	24	28	25	46	38
Herb	22	7	22	27	28	22	22	30	27
Total veg.	177	14	44	50	52	50	47	76	65
Exposed ground surface:									
Bare ground	-	2	6	2	1	3	1	2	4
Rock	-	1	1	-	-	1	-	-	-
Litter	43	83	56	48	49	53	52	35	34
Moss	12	-	-	4	2	1	1	4	2

Table 9-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 9-2.

Life-form component	Succession year								
	Pre	1	2	3	4	5	6	7	8
Tree	-	-	-	-	-	-	-	-	-
Shrub	156.3	1.4	7.8	7.1	8.4	9.7	8.7	19.2	14.7
Herb	1.8	.7	10.7	10.8	11.9	8.6	7.1	8.3	8.0
Total veg.	158.1	2.1	18.5	17.8	20.3	20.3	18.3	15.8	22.7

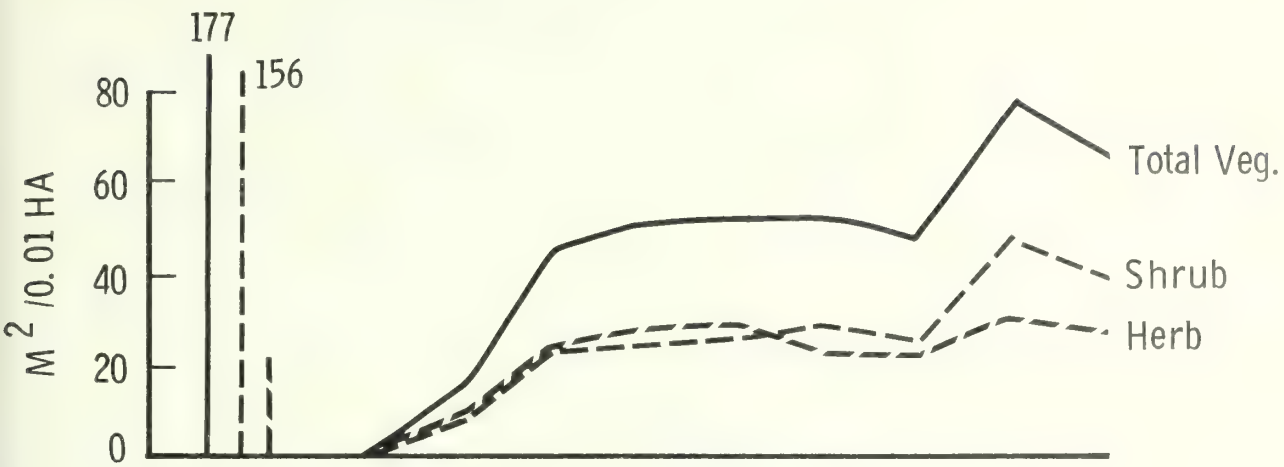


Figure 9-1. Vegetative cover.

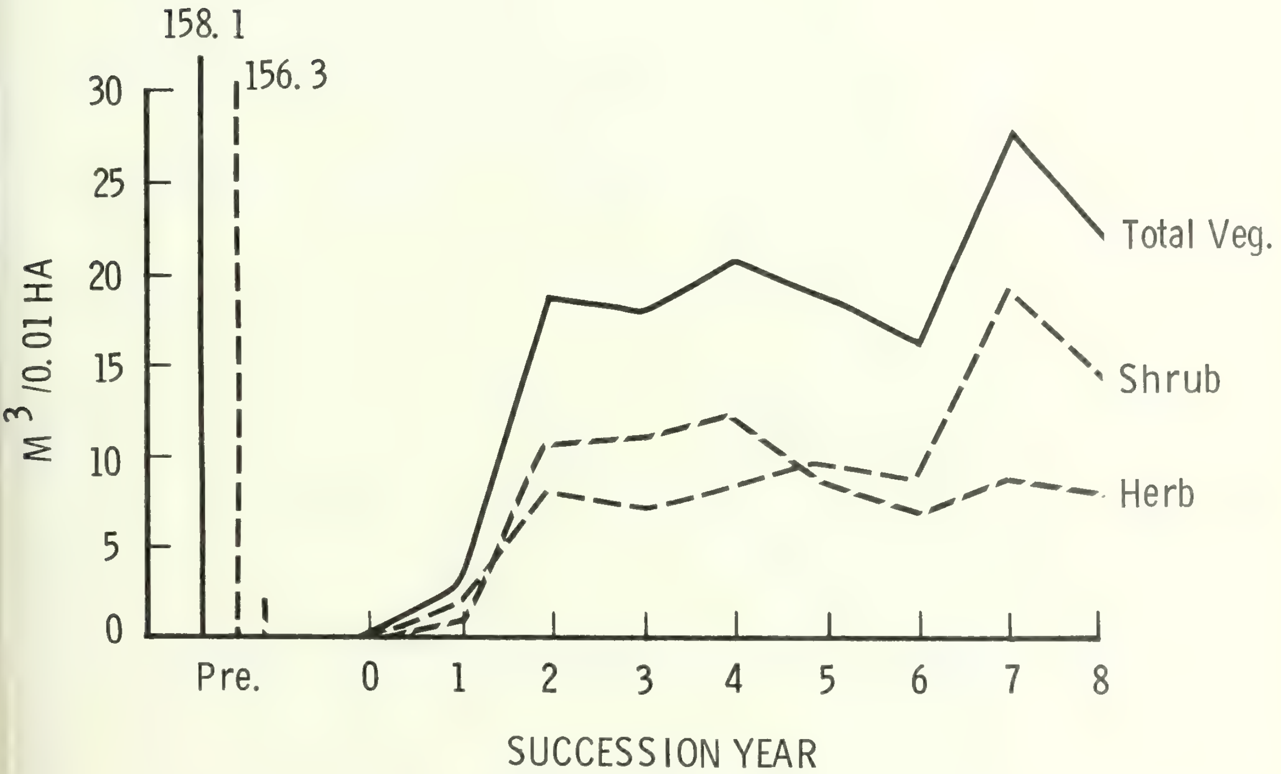


Figure 9-2. Vegetative volume.

MC: W-3 (A-20)

Table 9-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 9-3.

Species	Succession year								
	Pre	1	2	3	4	5	6	7	8
Acer glabrum	11	1	-	-	-	-	-	-	<1
Lonicera utahensis	2	-	-	-	-	-	-	1	1
Pachistima myrsinites	4	-	-	-	2	2	2	7	5
Ribes lacustre	-	-	-	-	-	-	-	-	1
Ribes viscosissimum	-	-	1	<1	<1	2	2	2	2
Rosa gymnocarpa	-	-	4	1	-	<1	<1	2	2
Rubus parviflorus	<1	4	9	9	10	11	5	12	11
Sambucus racemosa	-	-	1	<1	-	-	1	1	<1
Spiraea betulifolia	3	2	6	7	7	8	9	16	12
Taxus brevifolia	105	-	-	-	-	-	-	-	-
Vaccinium globulare	31	-	-	5	4	5	6	7	5
Total shrubs	156	7	21	23	24	28	25	46	38

Table 9-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 9-4.

Species	Succession year								
	Pre	1	2	3	4	5	6	7	8
Anaphalis margaritaceae	-	-	1	1	2	1	2	2	2
Arnica latifolia	1	1	2	2	1	-	-	2	1
Carex concinnoides	-	-	-	-	2	2	2	6	7
Carex rossii	-	-	1	1	2	2	2	2	3
Chimaphila umbellata	1	-	-	-	-	-	-	-	-
Cirsium vulgare	-	-	-	-	-	-	2	-	-
Epilobium angustifolium	-	-	10	15	12	8	5	9	7
Epilobium paniculatum	-	-	1	-	-	-	-	-	-
Geranium bicknellii	-	3	-	-	-	-	-	-	-
Goodyera oblongifolia	1	-	-	-	-	-	-	-	-
Gymnocarpium dryopteris	1	-	-	-	-	-	-	-	-
Linnaea borealis	8	-	-	-	-	-	1	1	2
Thalictrum occidentale	1	-	1	2	2	1	1	2	1
Tiarella trifoliata	1	-	-	-	-	-	-	-	-
Xerophyllum tenax	4	-	-	2	1	1	1	1	2
Misc. herbs	5	2	8	5	8	8	7	6	3
Total herbs	22	7	22	27	28	22	22	30	27

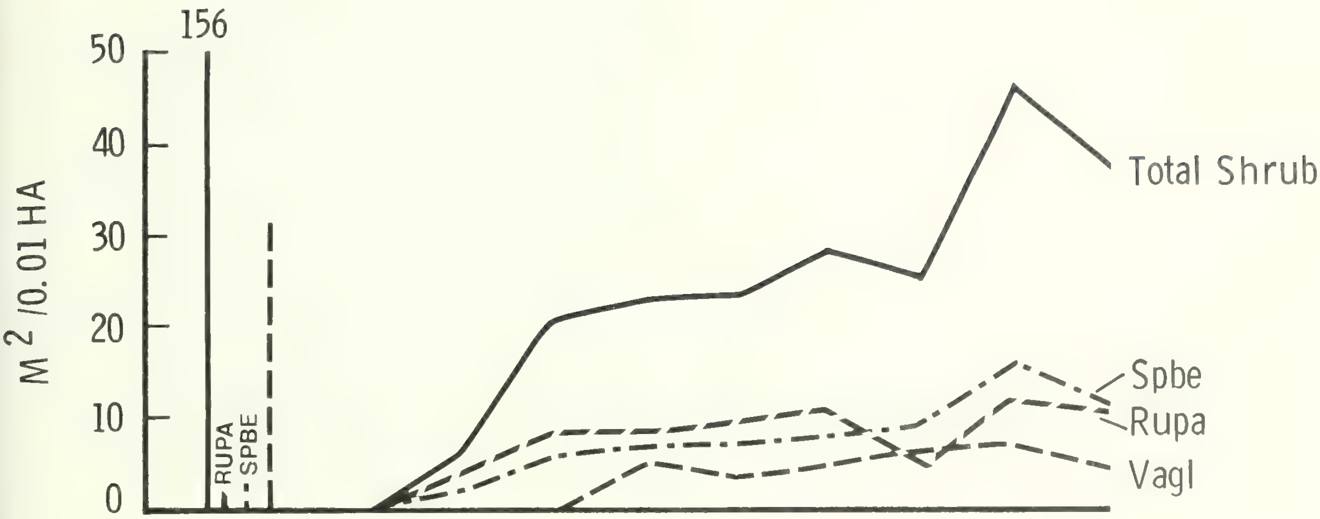


Figure 9-3. Shrub cover.

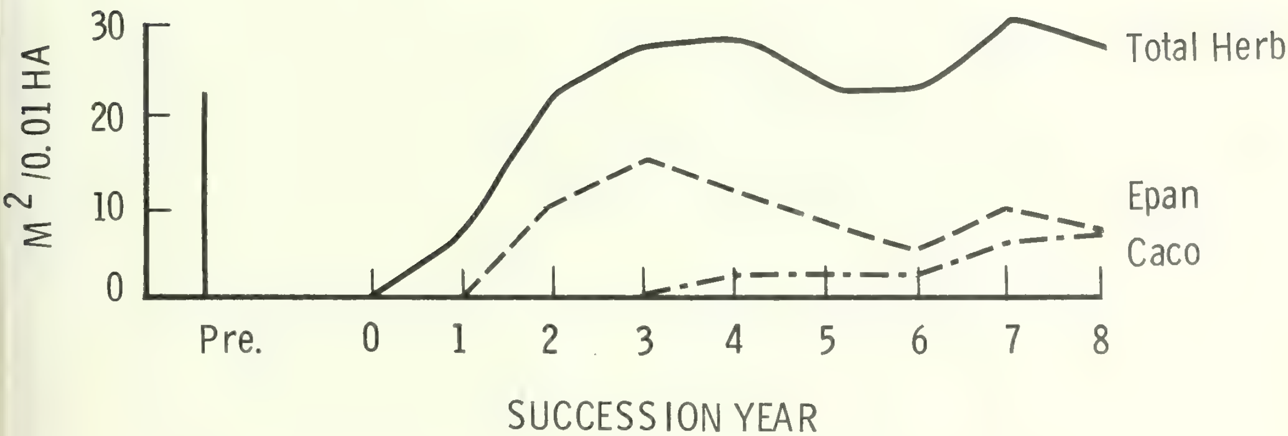


Figure 9-4. Herb cover.

MC: W-3 (A-20)

Table 9-5.--Volume development of shrub component (m^3/0.01 ha), fig. 9-5.

Species	Succession year								
	Pre	1	2	3	4	5	6	7	8
Acer glabrum	22.2	0.3	-	-	-	-	-	-	0.5
Lonicera utahensis	1.3	-	-	-	-	-	-	0.3	.3
Pachistima myrsinites	.7	-	-	-	0.2	0.3	0.6	1.6	1.6
Ribes lacustre	-	-	-	-	-	-	-	-	.7
Ribes viscosissimum	-	-	0.2	0.1	.2	.9	.9	1.5	1.1
Rosa gymnocarpa	-	-	1.2	.5	-	.2	<.1	1.2	.9
Rubus parviflorus	.2	.6	3.6	2.5	3.6	3.5	1.6	4.8	3.4
Sambucus racemosa	-	-	.4	.2	-	-	.6	.7	.2
Spiraea betulifolia	.9	.5	2.3	2.9	3.4	3.7	3.3	6.6	4.4
Taxus brevifolia	116.0	-	-	-	-	-	-	-	-
Vaccinium globulare	15.0	-	-	1.0	.9	1.2	1.6	2.4	1.5
Total shrubs	156.3	1.4	7.8	7.1	8.4	9.7	8.7	19.2	14.7

Table 9-6.--Volume development of herb component (m^3/0.01 ha), fig. 9-6.

Species	Succession year								
	Pre	1	2	3	4	5	6	7	8
Anaphalis margaritaceae	-	-	0.3	0.2	0.8	0.2	0.6	0.3	0.4
Arnica latifolia	0.1	0.1	.2	.2	.1	-	-	.2	.1
Carex concinnoides	-	-	-	-	.1	.2	.3	.6	.8
Carex rossii	-	-	.1	.1	.2	.4	.3	.4	.5
Chimaphila umbellata	<.1	-	-	-	-	-	-	-	-
Cirsium vulgare	-	-	-	-	-	-	.4	-	-
Epilobium angustifolium	-	-	7.9	8.4	8.3	5.8	3.2	4.9	4.8
Epilobium paniculatum	-	-	.3	-	-	-	-	-	-
Geranium bicknellii	-	.2	-	-	-	-	-	-	-
Goodyera oblongifolia	<.1	-	-	-	-	-	-	-	-
Gymnocarpium dryopteris	.1	-	-	-	-	-	-	-	-
Linnaea borealis	.4	-	-	-	-	-	<.1	<.1	.1
Thalictrum occidentale	.1	-	.4	.6	.7	.2	.3	.5	.2
Tiarella trifoliata	<.1	-	-	-	-	-	-	-	-
Xerophyllum tenax	.7	-	-	.6	.3	.3	.3	.2	.7
Misc. herbs	.4	.3	1.6	.7	1.2	1.4	1.6	1.0	.4
Total herbs	1.8	.7	10.7	10.8	11.9	8.6	7.1	8.3	8.0

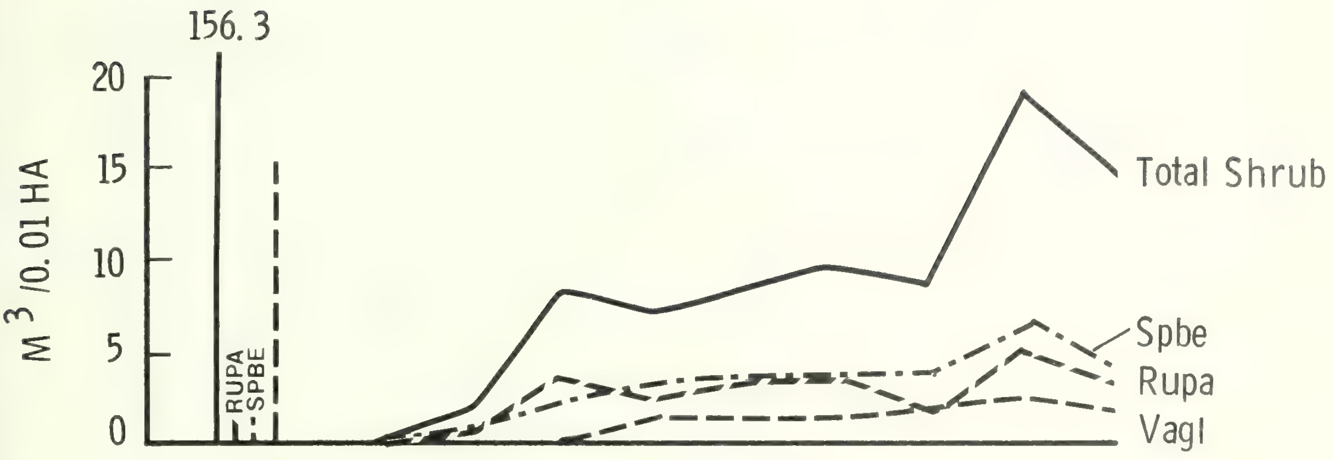


Figure 9-5. Shrub volume.

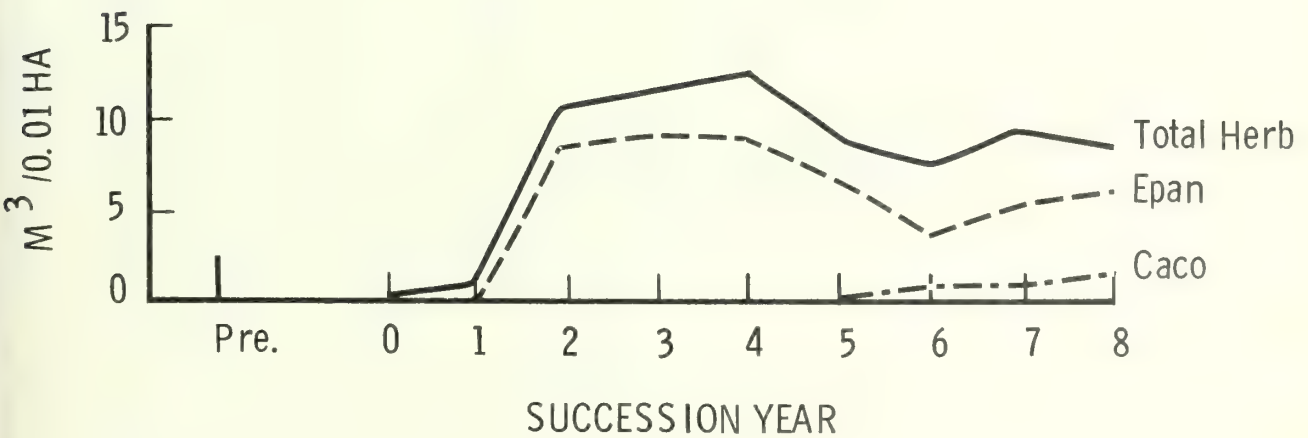


Figure 9-6. Herb volume.

MILLER CREEK: West-10 (1802-13 Area 17-1)

Site location and description: NE¼SW¼ Sec. 8, T32N R24W MPM.
Elevation: 4,700 ft; Exposure: West (Az. 260°); Slope: 30%
Habitat type: Abies lasiocarpa/Clintonia uniflora, Xerophyllum tenax Phase
Predisturbance forest stand: Laoc 50%, Pien 37%, Abla 10%, Psme 2% (Stand basal area: 3,023 cm^2/0.01 ha)
Disturbance treatment: Logged September 1967; Slashed October 1967;
Broadcast-burned: July 16, 1968 (Succession year 1:1969)
Fire intensity: 519 g water loss; Duff moisture: Upper 41%, Lower 78%; Postfire duff depth: 2.4 cm (48% of preburn depth)

Table 10-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 10-1.

Life-form component	Succession year								
	Pre	1	2	3	4	5	6	7	8
Tree	1	-	-	-	-	-	-	-	1
Shrub	20	3	12	13	15	19	24	27	28
Herb	43	7	57	62	35	33	36	45	40
Total veg.	64	10	69	75	50	52	60	72	69
Exposed ground surface:									
Bare ground	-	8	2	-	1	1	-	2	-
Rock	-	7	-	-	-	-	-	-	-
Litter	42	75	31	23	44	43	37	23	28
Moss	2	1	-	2	8	8	8	9	9

Table 10-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 10-2.

Life-form component	Succession year								
	Pre	1	2	3	4	5	6	7	8
Tree	0.4	-	-	-	-	-	-	-	1.1
Shrub	12.4	0.7	3.8	3.9	4.8	5.8	7.6	10.6	11.8
Herb	5.2	.9	20.4	16.4	12.1	9.8	9.0	13.2	10.2
Total veg.	18.1	1.8	24.2	20.3	16.8	15.6	16.6	23.9	23.0

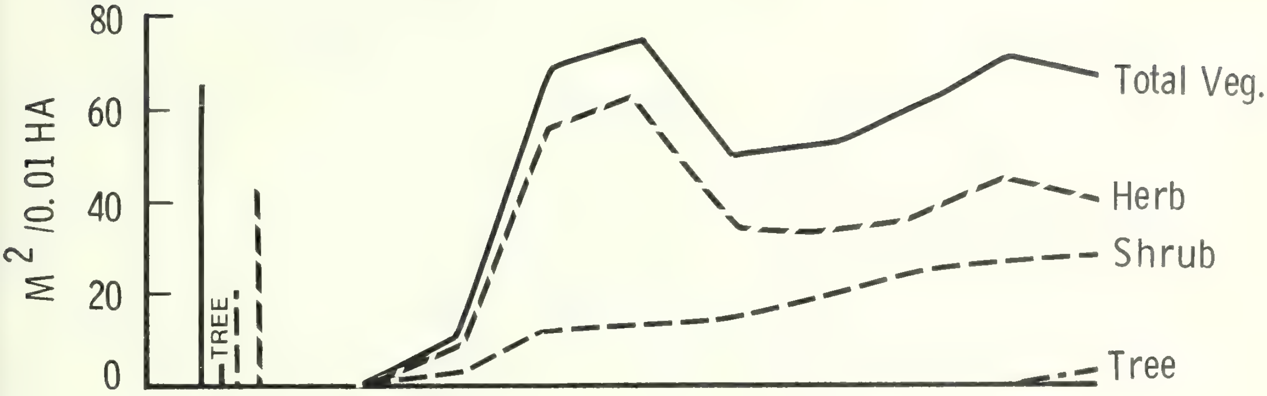


Figure 10-1. Vegetative cover.

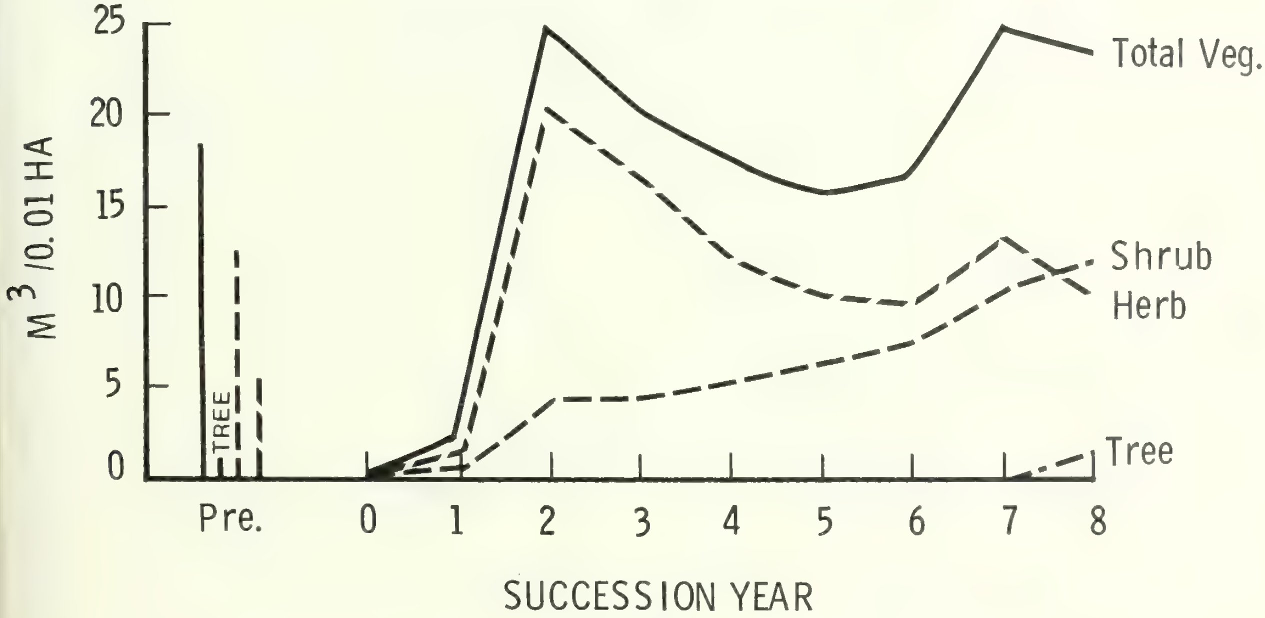


Figure 10-2. Vegetative volume.

Table 10-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 10-3.

Species	Succession year								
	Pre	1	2	3	4	5	6	7	8
Acer glabrum	3	-	-	-	-	-	<1	1	1
Amelanchier alnifolia	-	<1	-	-	-	-	-	-	-
Lonicera utahensis	3	-	-	-	2	2	2	3	3
Pachistima myrsinites	10	-	-	2	2	3	7	9	8
Rubus parviflorus	-	-	4	-	-	-	2	2	2
Salix scouleriana	-	-	-	-	-	-	<1	1	1
Spiraea betulifolia	<1	2	7	10	10	9	10	10	10
Vaccinium globulare	4	-	1	2	2	4	2	2	4
Total shrubs	20	3	12	13	15	19	24	27	28

Table 10-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 10-4.

Species	Succession year								
	Pre	1	2	3	4	5	6	7	8
Arnica latifolia	11	3	8	8	2	1	-	-	1
Berberis repens	1	-	2	2	2	2	1	2	1
Carex concinnoides	1	-	1	1	2	4	8	9	14
Chimaphila umbellata	2	-	-	-	-	-	-	-	-
Epilobium angustifolium	-	1	17	25	15	10	12	15	9
Epilobium paniculatum	-	-	18	16	-	-	-	-	-
Linnaea borealis	8	-	-	-	-	-	-	-	-
Viola orbiculata	2	-	1	1	-	-	-	-	-
Xerophyllum tenax	8	2	6	8	9	13	12	12	14
Misc. herbs	12	1	3	2	5	3	3	6	1
Total herbs	43	7	57	62	35	33	36	45	40

Figure 10-3. Shrub cover.

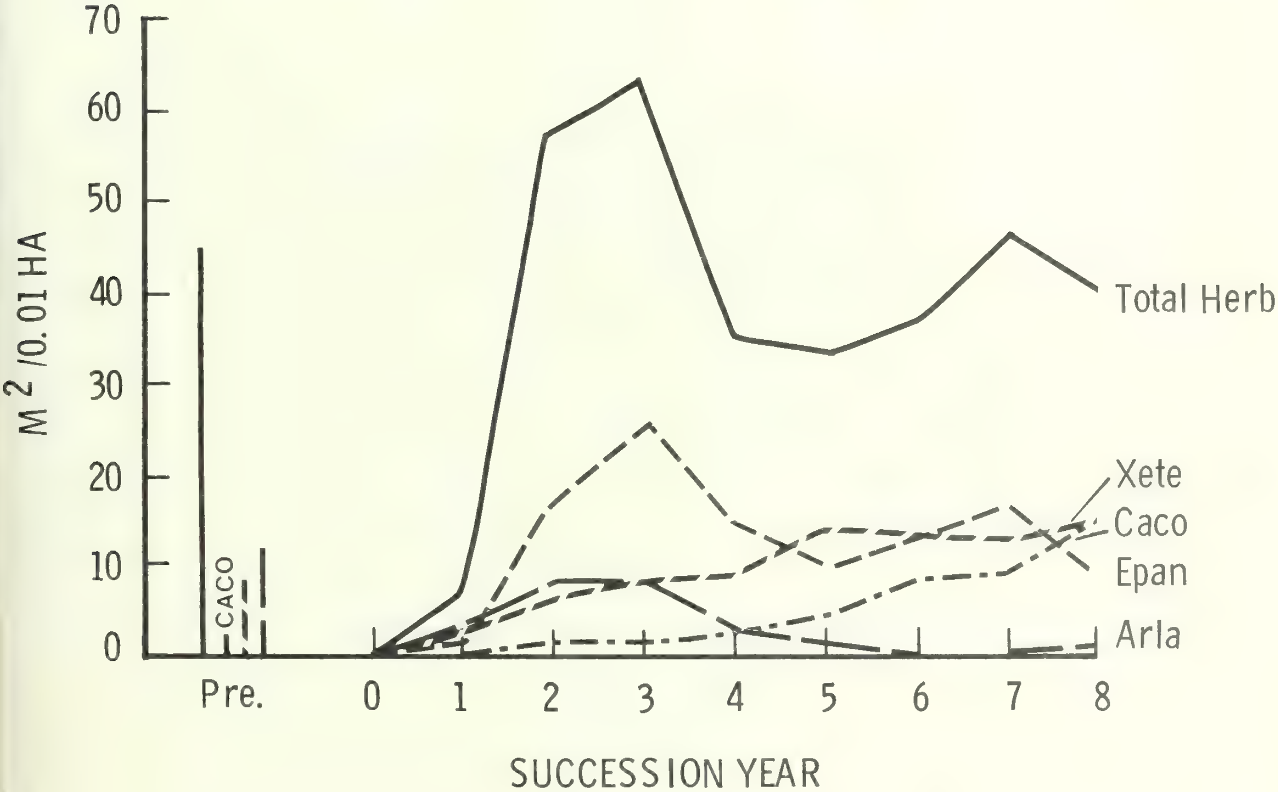


Figure 10-4. Herb cover.

Table 10-5.--Volume development of shrub component (m^3/0.01 ha), fig. 10-5.

Species	Successsion year								
	Pre	1	2	3	4	5	6	7	8
Acer glabrum	6.3	-	-	-	-	-	0.6	1.1	1.2
Amelanchier alnifolia	-	0.1	-	-	-	-	-	-	-
Lonicera utahensis	2.0	-	-	-	1.0	1.2	1.1	1.5	1.7
Pachistima myrsinites	2.3	-	-	0.2	.3	.6	1.4	3.1	2.1
Rubus parviflorus	-	-	1.2	-	-	-	.4	.4	.7
Salix scouleriana	-	-	-	-	-	-	.3	.9	1.7
Spiraea betulifolia	.1	.6	2.4	3.3	3.1	3.0	3.1	3.1	3.5
Vaccinium globulare	1.7	-	.2	.3	.4	1.0	.7	.5	.8
Total shrubs	12.4	.7	3.8	3.9	4.8	5.8	7.6	10.6	11.8

Table 10-6.--Volume development of herb component (m^3/0.01 ha), fig. 10-6.

Species	Succession year								
	Pre	1	2	3	4	5	6	7	8
Arnica latifolia	1.2	0.4	3.7	1.5	0.2	<0.1	-	-	0.1
Berberis repens	.1	-	.2	.2	.2	.1	0.1	0.2	.1
Carex concinnoides	<.1	-	.1	.1	.2	.4	.8	.9	1.4
Chimaphila umbellata	.2	-	-	-	-	-	-	-	-
Epilobium angustifolium	-	.1	6.9	11.4	8.9	5.6	5.3	8.0	4.8
Epilobium paniculatum	-	-	7.5	1.1	-	-	-	-	-
Linnaea borealis	.4	-	-	-	-	-	-	-	-
Viola orbiculata	.1	-	<.1	<.1	-	-	-	-	-
Xerophyllum tenax	2.2	.4	1.2	1.6	1.8	2.9	2.4	3.3	3.7
Misc. herbs	1.0	.1	.8	.4	.8	.8	.4	.7	.2
Total herbs	5.2	.9	20.4	16.4	12.1	9.8	9.0	13.2	10.2

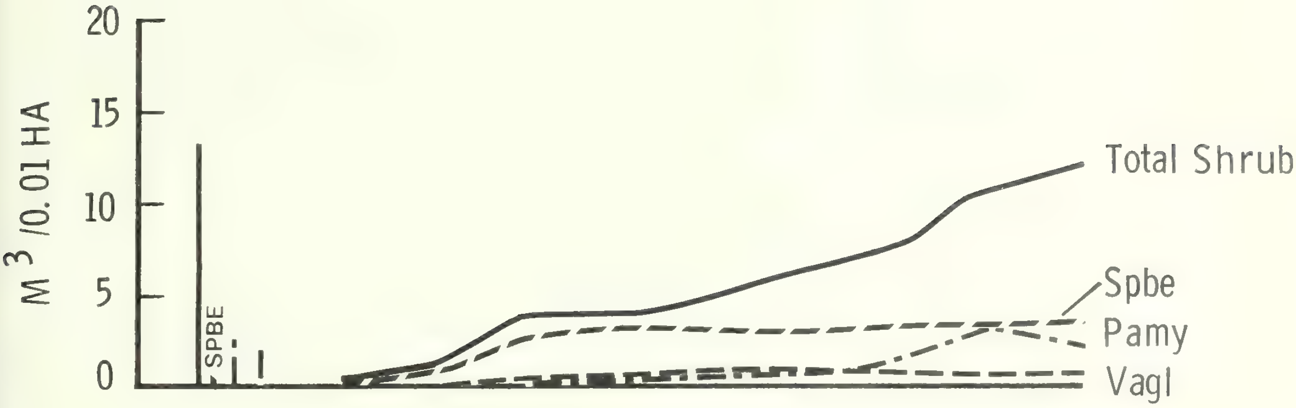


Figure 10-5. Shrub volume.

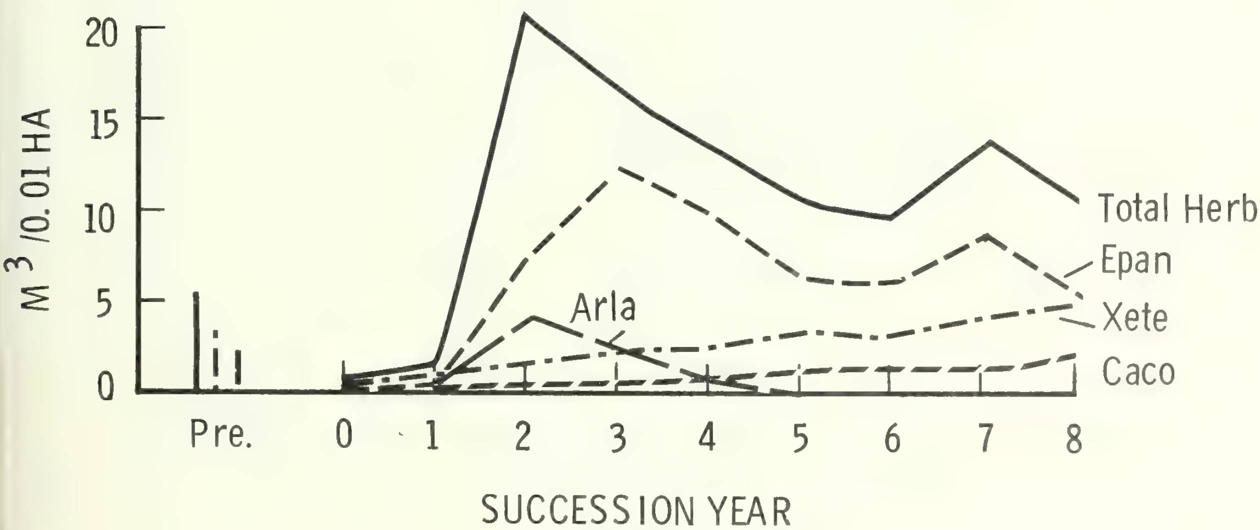


Figure 10-6. Herb volume.

MILLER CREEK: West-15 (1802-13 Area 17-3)

Site location and description: NE¼SW¼ Sec. 8, T32N R24W MPM.
Elevation: 4,600 ft; Exposure: West (Az. 270¼); Slope: 25%
Habitat type: Abies lasiocarpa/Clintonia uniflora, Xerophyllum tenax Phase
Predisturbance forest stand: Laoc 70%, Pien 16%, Abla 14%, Psme <1%
Stand basal area: 3,771 cm^2/0.01 ha)
Disturbance treatment: Logged January 1968; Slashed February 1968;
Broadcast-burned: October 2, 1968 (Succession year 1:1969)
Fire intensity: 228 g water loss; Duff moisture: Upper 164%, Lower 212%; Postfire duff depth: 6.4 cm (89% of preburn depth)

Table 11-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 11-1.

Life-form component	Succession year								
	Pre	1	2	3	4	5	6	7	8
Tree	2	-	-	-	-	-	-	-	-
Shrub	56	1	10	17	16	19	26	32	34
Herb	66	39	67	46	47	42	45	46	51
Total veg.	124	40	76	62	63	61	71	79	84
Exposed ground surface:									
Bare ground	-	-	-	-	-	-	-	-	-
Rock	-	-	-	-	-	-	-	-	-
Litter	11	60	27	43	45	47	37	30	30
Moss	1	-	-	-	-	-	-	6	-

Table 11-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 11-2.

Life-form component	Succession year								
	Pre	1	2	3	4	5	6	7	8
Tree	0.8	-	-	-	-	-	-	-	-
Shrub	97.3	0.4	3.5	6.0	9.7	8.7	12.2	18.3	18.4
Herb	10.6	3.9	26.4	7.4	8.8	6.7	7.6	9.6	8.3
Total veg.	108.6	4.3	29.9	13.4	18.5	15.4	19.7	27.9	26.7

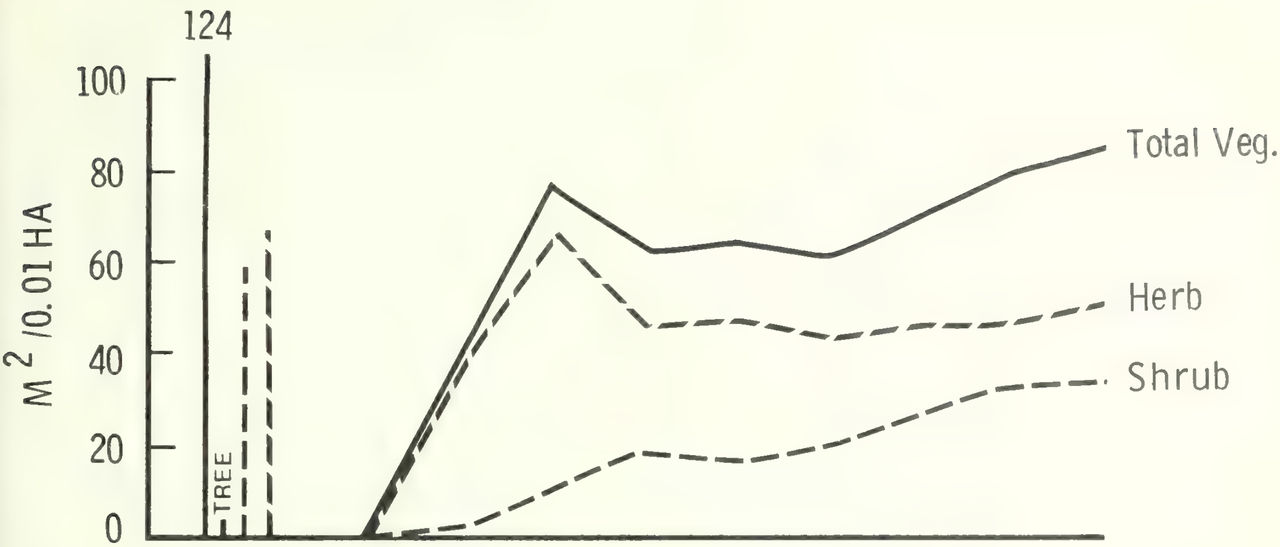


Figure 11-1. Vegetative cover.

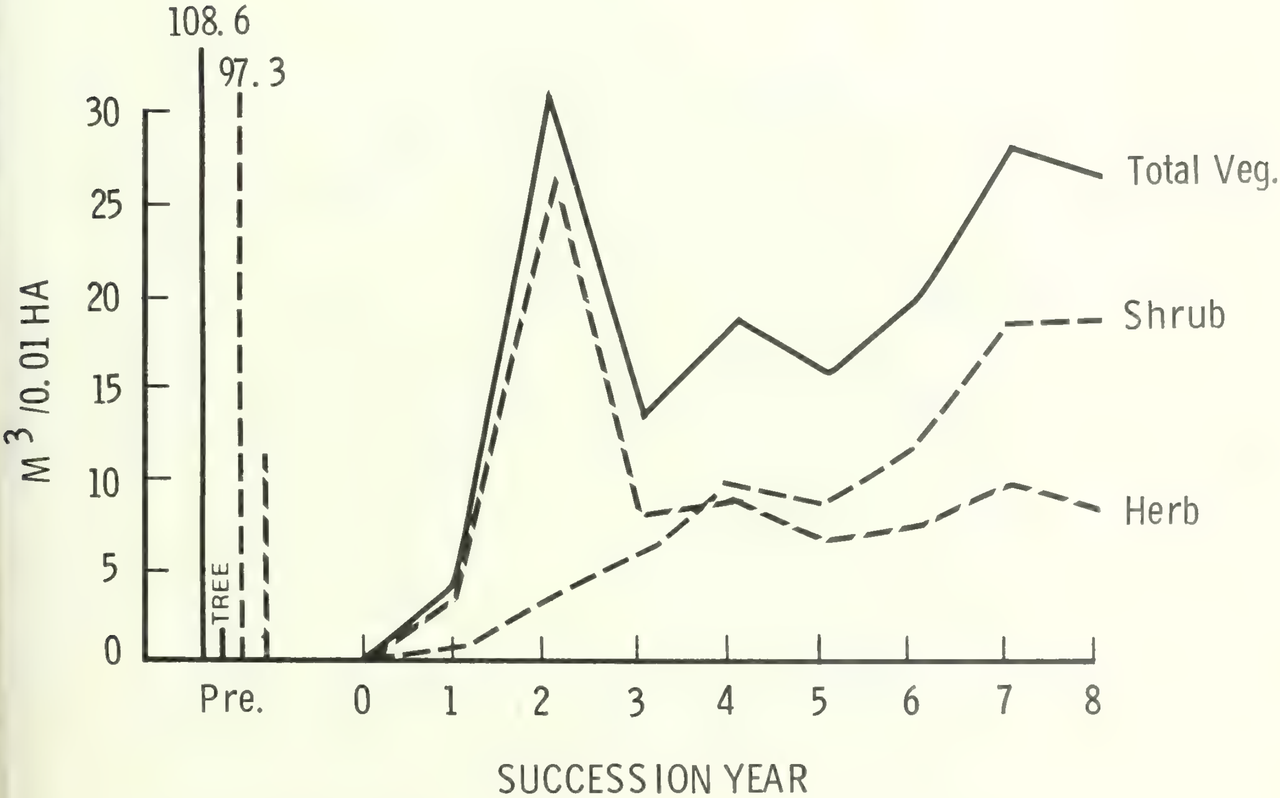


Figure 11-2. Vegetative volume.

Table 11-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 11-3.

Species	Succession year								
	Pre	1	2	3	4	5	6	7	8
Acer glabrum	18	-	1	1	4	2	3	4	2
Lonicera utahensis	2	-	1	2	3	5	5	7	8
Pachistima myrsinites	11	-	-	-	1	2	5	7	8
Rosa gymnocarpa	2	<1	4	7	4	4	5	8	3
Rubus parviflorus	1	1	2	1	2	2	3	2	2
Salix scouleriana	-	-	-	-	-	-	<1	<1	2
Spiraea betulifolia	1	-	1	3	2	3	2	1	5
Symphoricarpos albus	-	-	-	-	-	-	-	-	<1
Taxus brevifolia	8	-	-	-	-	-	-	-	-
Vaccinium globulare	14	-	1	3	1	1	2	3	2
Total shrubs	56	1	10	17	16	19	26	32	34

Table 11-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 11-4.

Species	Succession year								
	Pre	1	2	3	4	5	6	7	8
Arnica latifolia	37	32	54	30	17	2	-	-	-
Berberis repens	3	-	1	3	2	4	4	6	3
Carex concinnoides	-	-	2	2	8	11	17	18	24
Chimaphila umbellata	2	-	-	-	-	-	-	-	-
Clintonia uniflora	2	-	-	-	-	-	-	-	-
Epilobium angustifolium	-	-	2	2	6	2	6	8	4
Geranium bicknellii	-	5	-	-	-	-	-	-	-
Linnaea borealis	6	-	1	1	2	2	2	2	5
Pyrola secunda	1	-	-	-	-	-	-	-	-
Thalictrum occidentale	2	-	-	-	-	-	1	1	1
Viola orbiculata	1	-	-	-	-	-	-	-	-
Xerophyllum tenax	6	-	2	2	6	7	6	6	7
Misc. herbs	6	2	5	4	7	12	9	5	7
Total herbs	66	39	67	46	47	42	45	47	51

MC: W-15 (A-17-3)

Figure 11-3. Shrub cover.

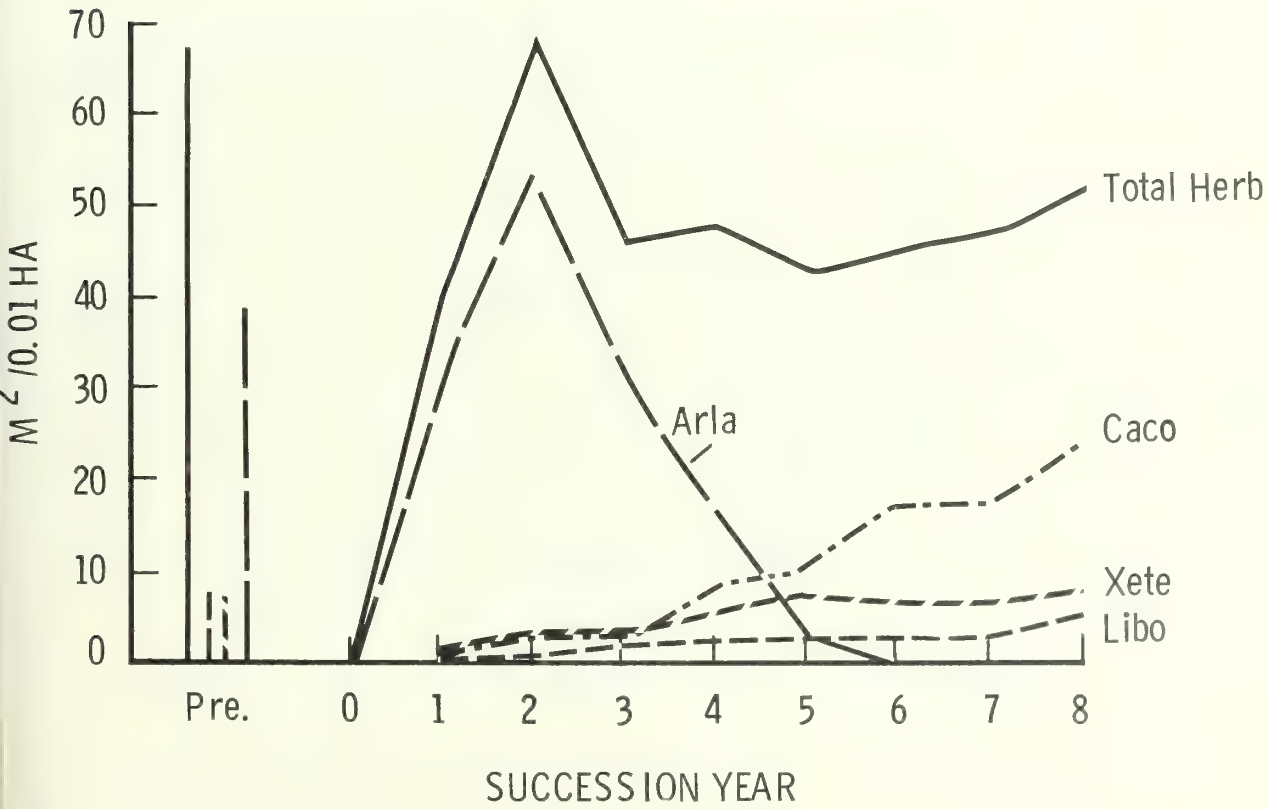


Figure 11-4. Herb cover.

Table 11-5.--Volume development of shrub component (m^3/0.01 ha), fig. 11-5.

Species	Succession year								
	Pre	1	2	3	4	5	6	7	8
Acer glabrum	65.3	-	0.5	1.2	5.2	2.0	3.9	6.1	4.0
Lonicera utahensis	1.1	-	.6	1.5	1.9	3.6	3.3	5.4	6.0
Pachistima myrsinites	2.5	-	-	-	.2	.4	1.3	1.7	2.5
Rosa gymnocarpa	.8	0.2	1.4	1.6	1.4	1.2	1.5	3.4	1.3
Rubus parviflorus	.1	.1	.4	.1	.3	.4	.7	.7	.4
Salix scouleriana	-	-	-	-	-	-	.3	.2	2.0
Spiraea betulifolia	.2	-	.6	1.0	.6	1.0	.6	.2	1.6
Symphoricarpos albus	-	-	-	-	-	-	-	-	<.1
Taxus brevifolia	19.8	-	-	-	-	-	-	-	-
Vaccinium globulare	7.4	-	.1	.7	.2	.2	.6	.7	.6
Total shrubs	97.3	.4	3.5	6.0	9.7	8.7	12.2	18.3	18.4

Table 11-6.-- Volume development of herb component (m^3/0.01 ha), fig. 11-6.

Species	Succession year								
	Pre	1	2	3	4	5	6	7	8
Arnica latifolia	6.8	3.2	24.2	4.6	2.0	0.2	-	-	-
Berberis repens	.7	-	.1	.4	.3	.4	0.5	0.6	0.4
Carex concinnoides	-	-	.1	.1	.8	1.1	1.8	1.8	2.6
Chimaphila umbellata	.2	-	-	-	-	-	-	-	-
Clintonia uniflora	.1	-	-	-	-	-	-	-	-
Epilobium angustifolium	-	-	.8	1.2	3.3	1.5	2.5	4.7	2.1
Geranium bicknellii	-	.4	-	-	-	-	-	-	-
Linnaea borealis	.3	-	<.1	<.1	.1	.1	.1	.1	.2
Pyrola secunda	<.1	-	-	-	-	-	-	-	-
Thalictrum occidentale	.6	-	-	-	-	-	.2	.4	.1
Viola orbiculata	<.1	-	-	-	-	-	-	-	-
Xerophyllum tenax	1.4	-	.5	.5	1.1	1.3	1.2	1.3	1.7
Misc. herbs	.5	.3	.7	.5	1.2	2.1	1.4	.6	1.2
Total herbs	10.6	3.9	26.4	7.4	8.8	6.7	7.6	9.6	8.3

Figure 11-5. Shrub volume.

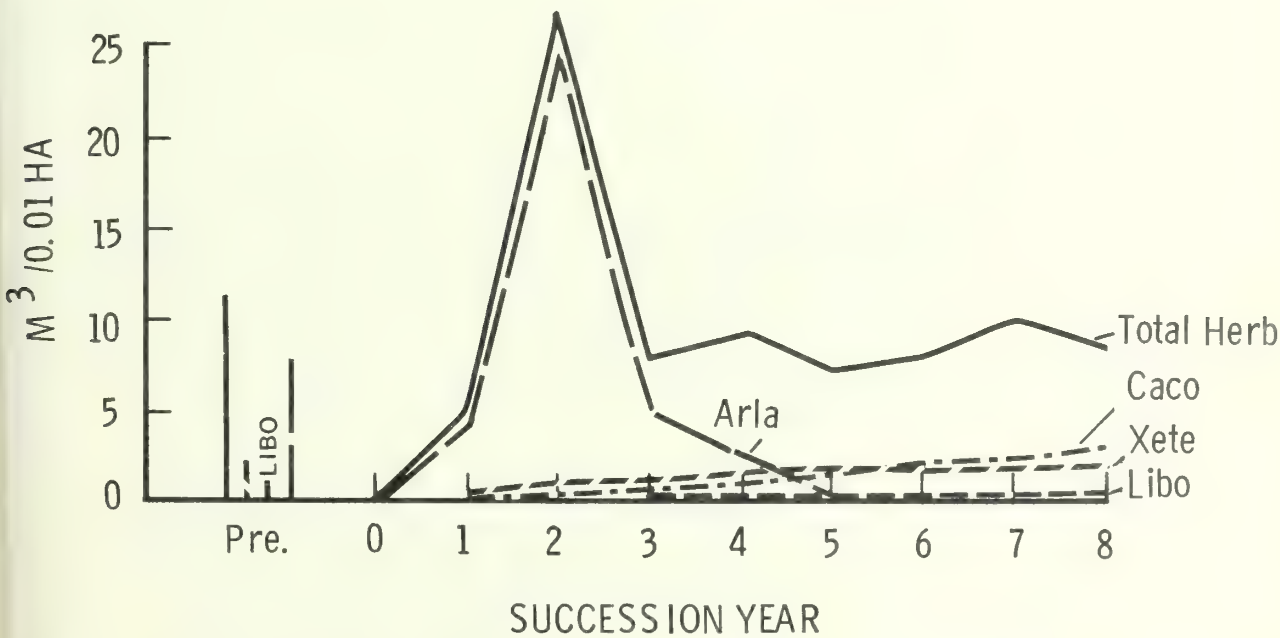


Figure 11-6. Herb volume.

NEWMAN RIDGE: North-2 (1802-13 Area 26)

Site location and description: SW¼SE¼ Sec. 26, T18N R29W MPM.
Elevation: 5,000 ft; Exposure: Northeast (Az. 41¼); Slope: 60%
Habitat type: Thuja plicata/Clintonia uniflora, Menziesia ferruginea Phase
Predisturbance forest stand: Laoc 61%, Psme 14%, Abgr 11%, Abla 8%, Thpl 3%, Pien 2% (Stand basal area: 6,788 cm^2/0.01 ha)
Disturbance treatment: Logged August 1968; Slashed June 1969;
Broadcast-burned: July 25, 1969 (Succession year 1:1970)
Fire intensity: 1,297 g water loss; Duff moisture: Upper 16%, Lower 63%; Postfire duff depth: 2.7 cm (49% of preburn depth)

Table 12-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 12-1.

Life-form component	Succession year							
	Pre	1	2	3	4	5	6	7
Tree	-	1	1	-	-	-	-	2
Shrub	24	13	17	13	35	35	49	49
Herb	49	32	62	56	49	48	54	53
Total veg.	73	46	80	68	84	83	103	104
Exposed ground surface:								
Bare ground	-	16	-	-	-	-	-	-
Rock	-	-	1	-	-	-	-	-
Litter	50	32	13	24	20	17	10	11
Moss	-	7	6	10	17	10	10	11

Table 12-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 12-2.

Life-form component	Succession year							
	Pre	1	2	3	4	5	6	7
Tree	-	0.1	0.2	-	-	-	-	2.5
Shrub	24.6	1.5	3.3	3.8	18.4	16.0	27.6	30.8
Herb	7.9	5.9	20.4	15.5	14.2	15.9	13.5	15.8
Total veg.	32.5	7.6	23.8	19.3	32.6	32.0	41.1	49.2

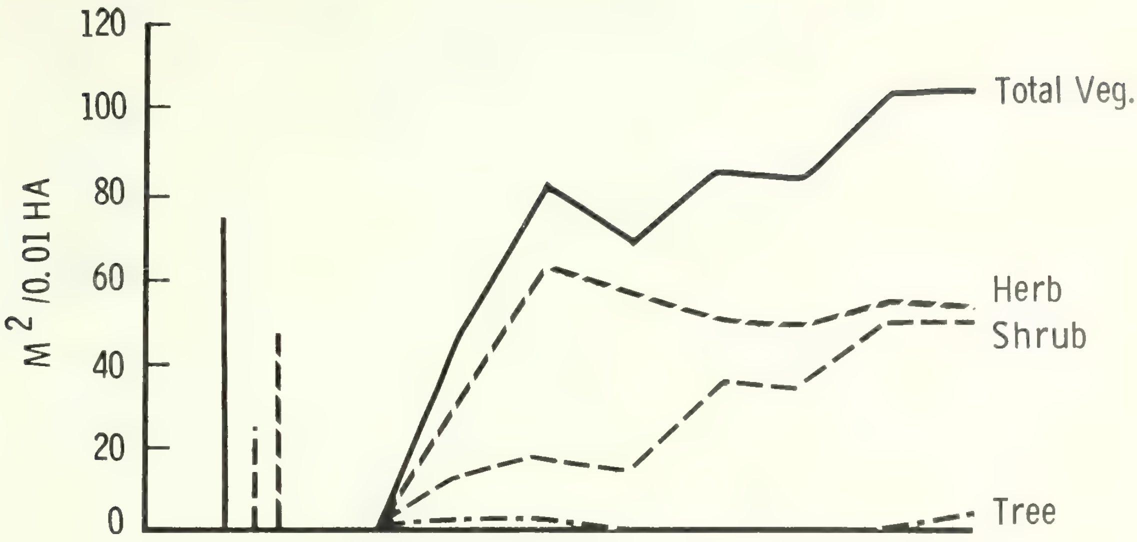


Figure 12-1. Vegetative cover.

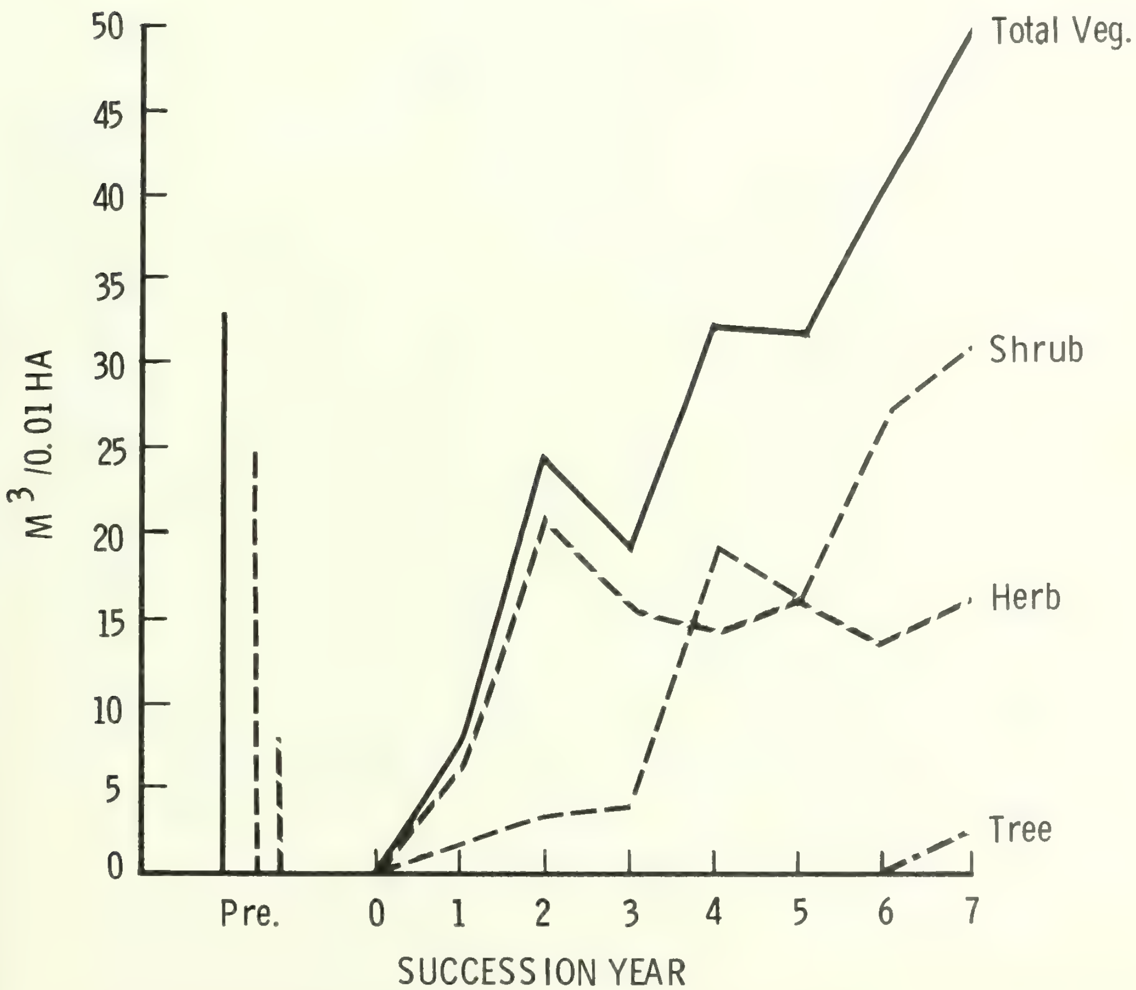


Figure 12-2. Vegetative volume.

Table 12-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 12-3.

Species	Succession year							
	Pre	1	2	3	4	5	6	7
Acer glabrum	3	-	-	-	<1	-	-	-
Amelanchier alnifolia	-	-	-	-	1	-	-	-
Lonicera utahensis	2	-	-	-	-	-	-	-
Menziesia ferruginea	10	-	-	-	-	-	-	-
Pachistima myrsinites	-	-	-	-	-	-	-	1
Ribes viscosissimum	-	1	1	1	11	8	10	8
Rubus parviflorus	-	12	14	8	13	17	21	21
Salix scouleriana	-	-	-	2	6	7	14	16
Sambucus racemosa	-	-	1	-	<1	-	-	1
Vaccinium globulare	9	1	1	2	3	2	4	3
Total shrubs	24	13	17	13	35	35	49	49

Table 12-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 12-4.

Species	Succession year							
	Pre	1	2	3	4	5	6	7
Anemone piperi	-	1	11	11	5	1	3	-
Arenaria macrophylla	-	-	-	-	1	-	2	-
Arnica latifolia	5	5	5	3	2	1	-	2
Carex concinnoides	-	-	-	-	2	2	2	4
Carex geyeri	-	-	-	-	-	-	-	1
Carex rossii	-	1	8	9	11	12	8	8
Clintonia uniflora	3	-	-	-	-	-	2	2
Coptis occidentalis	17	-	1	1	1	2	2	3
Disporum hookeri	6	2	5	3	3	7	5	7
Epilobium angustifolium	-	5	11	10	12	12	12	15
Epilobium paniculatum	-	-	5	1	-	-	-	-
Epilobium watsonii	-	3	2	2	-	-	-	-
Galium triflorum	1	-	-	-	-	-	-	-
Geranium bicknellii	-	6	1	-	-	-	-	-
Hieracium albiflorum	-	-	-	-	-	-	2	3
Osmorhiza chilensis	1	-	-	-	-	-	-	-
Thalictrum occidentale	2	2	3	4	3	6	2	2
Trillium ovatum	1	-	1	-	-	-	1	-
Misc. herbs	12	7	9	11	9	7	12	6
Total herbs	49	32	62	56	49	48	54	53

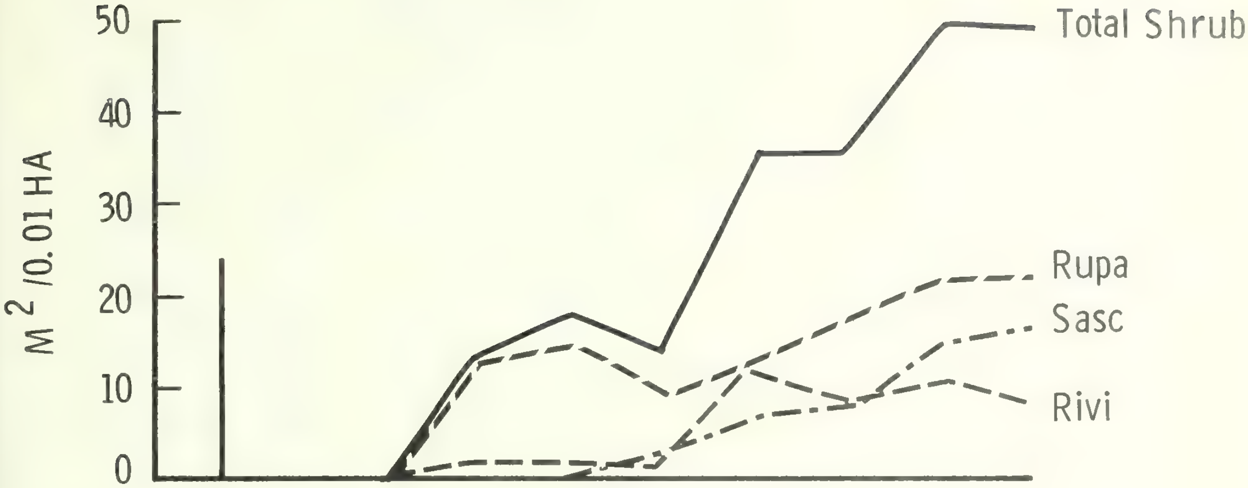


Figure 12-3. Shrub cover.

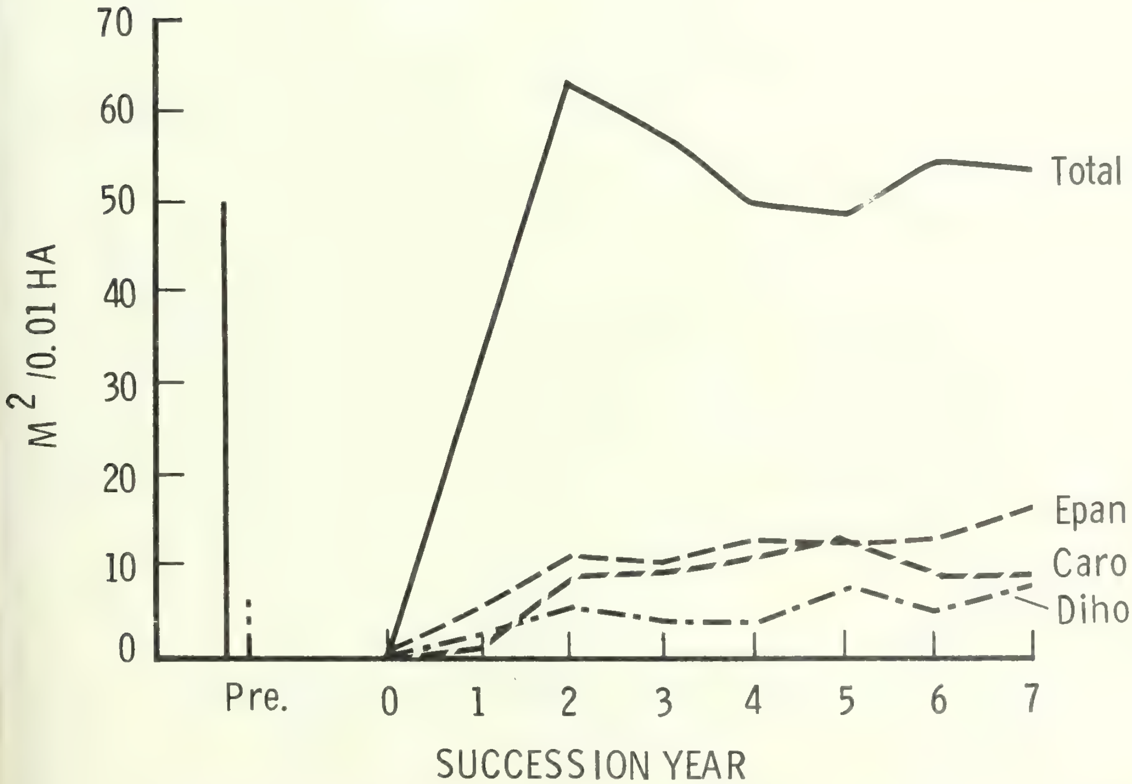


Figure 12-4. Herb cover.

NR: N-2 (A-26)

Table 12-5.--Volume development of shrub component (m^3/0.01 ha), fig. 12-5.

Species	Succession year							
	Pre	1	2	3	4	5	6	7
Acer glabrum	8.4	-	-	-	0.3	-	-	-
Amelanchier alnifolia	-	-	-	-	.9	-	-	-
Lonicera utahensis	1.5	-	-	-	-	-	-	-
Menziesia ferruginea	9.9	-	-	-	-	-	-	-
Pachistima myrsinites	-	-	-	-	-	-	-	0.1
Ribes viscosissimum	-	0.1	0.2	0.2	6.6	4.0	6.0	5.1
Rubus parviflorus	-	1.3	2.5	1.8	3.7	4.7	5.4	6.1
Salix scouleriana	-	-	-	1.2	5.6	6.7	14.9	17.6
Sambucus racemosa	-	-	.3	-	.1	-	-	.5
Vaccinium globulare	4.8	.2	.2	.5	1.1	.8	1.3	1.4
Total shrubs	24.6	1.5	3.3	3.8	18.4	16.0	27.6	30.8

Table 12-6.--Volume development of herb component (m^3/0.01 ha), fig. 12-6.

Species	Succession year							
	Pre	1	2	3	4	5	6	7
Anemone piperi	-	<0.1	1.4	1.5	0.6	0.1	0.3	-
Arenaria macrophylla	-	-	-	-	<.1	-	.2	-
Arnica latifolia	0.8	.5	2.4	.3	.2	.1	-	0.1
Carex concinnoides	-	-	-	-	.2	.2	.2	.4
Carex geyeri	-	-	-	-	-	-	-	.2
Carex rossii	-	<.1	1.2	1.3	1.2	1.5	1.0	1.1
Clintonia uniflora	.2	-	-	-	-	-	.1	.1
Coptis occidentalis	2.2	-	.1	<.1	<.1	.2	.1	.2
Disporum hookeri	1.7	.3	1.8	1.1	1.3	1.8	1.3	1.8
Epilobium angustifolium	-	2.0	6.0	7.4	8.0	9.2	7.8	9.6
Epilobium paniculatum	-	-	2.1	<.1	-	-	-	-
Epilobium watsonii	-	1.1	1.2	.1	-	-	-	-
Galium triflorum	<.1	-	-	-	-	-	-	-
Geranium bicknellii	-	1.0	.2	-	-	-	-	-
Hieracium albiflorum	-	-	-	-	-	-	.3	.3
Osmorhiza chilensis	.2	-	-	-	-	-	-	-
Thalictrum occidentale	1.4	.5	1.5	1.5	1.2	1.9	1.0	.6
Trillium ovatum	.2	-	.2	-	-	-	.1	-
Misc. herbs	1.2	.4	1.7	2.2	1.4	.8	1.1	1.4
Total herbs	7.9	5.9	20.4	15.5	14.2	15.9	13.5	15.8

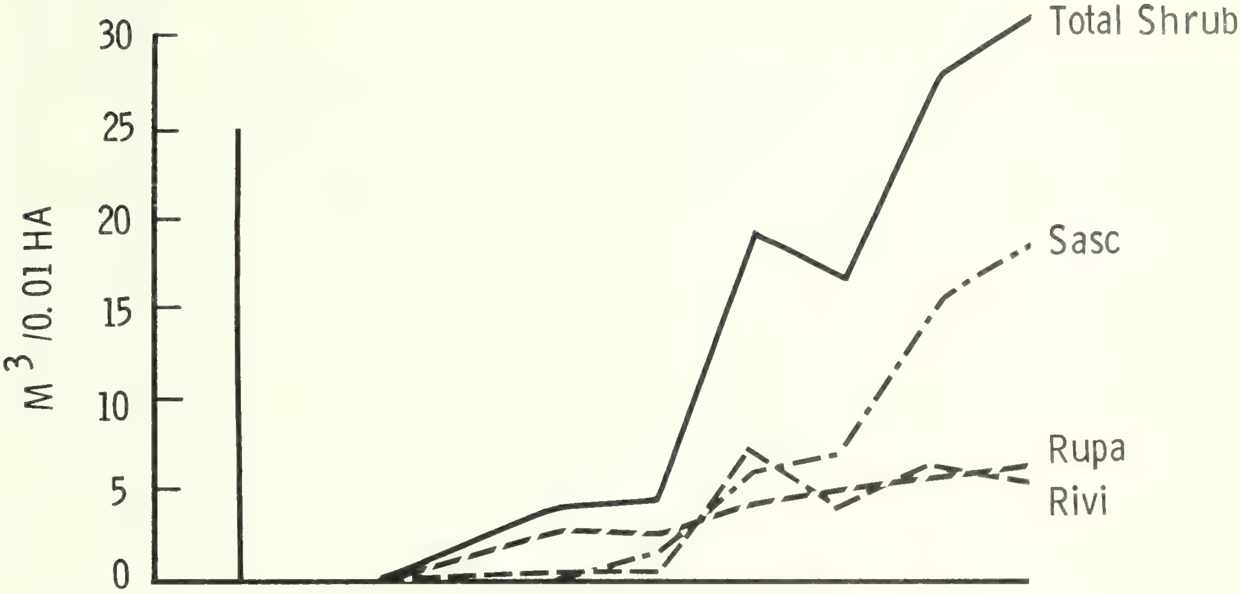


Figure 12-5. Shrub volume.

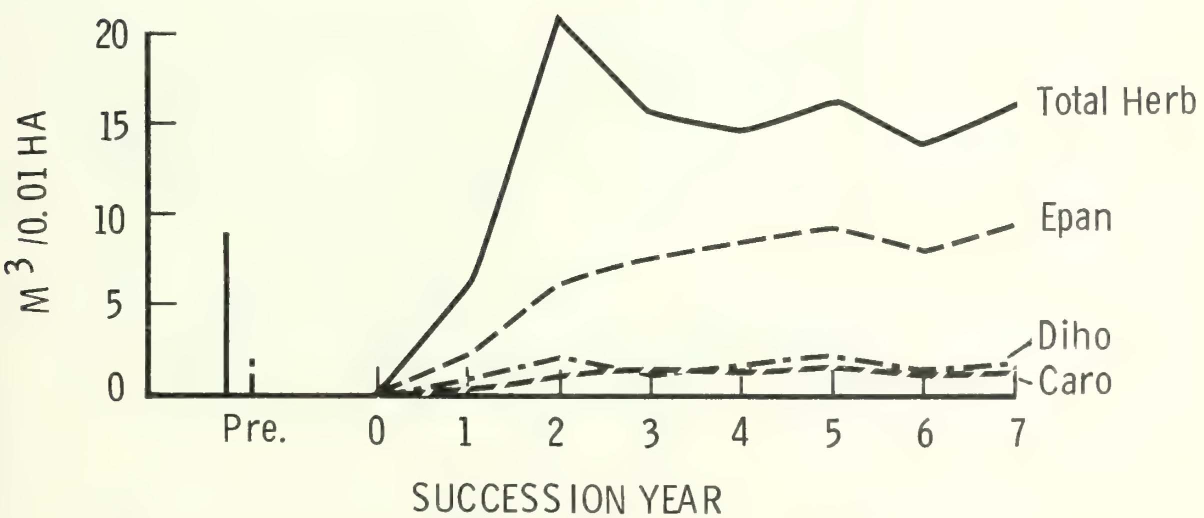


Figure 12-6. Herb volume.

NEWMAN RIDGE: East-3 (1802-13 Area 27)

Site location and description: SW¼NW¼ Sec. 35, T18N R29W MPM.
Elevation: 5,300 ft; Exposure: East (Az. 104°); Slope: 55%
Habitat type: Abies grandis/Clintonia uniflora, Xerophyllum tenax Phase
Predisturbance forest stand: Pico 38%, Psme 26%, Laoc 16%, Pien 12%, Abla 5%, Abgr 3% (Stand basal area 4,207 cm^2/0.01 ha)
Disturbance treatment: Logged June 1969; Slashed June 1969;
Broadcast-burned: July 25, 1969 (Succession year 1:1970)
Fire intensity: 820 g water loss; Duff moisture: Upper 16%, Lower 63%; Postfire duff depth: 2.0 cm (65% of preburn depth)

Table 13-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 13-1.

Life-form component	Succession year							
	Pre	1	2	3*	4	5	6	7
Tree	-	-	-		-	1	-	2
Shrub	45	11	12		17	34	46	40
Herb	29	20	37		41	44	39	37
Total veg.	74	31	48		58	78	85	80
Exposed ground surface:								
Bare ground	-	17	10		5	3	5	-
Rock	-	-	-		-	-	-	-
Litter	52	46	34		24	18	22	16
Moss	-	7	11		16	9	12	25

Table 13-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 13-2.

Life-form component	Succession year							
	Pre	1	2	3*	4	5	6	7
Tree	-	-	-		-	0.3	-	1.7
Shrub	29.0	1.0	3.5		6.2	12.0	25.1	19.8
Herb	3.8	2.2	9.7		12.8	12.9	10.7	10.6
Total veg.	32.8	3.2	13.2		19.0	25.2	35.7	32.1

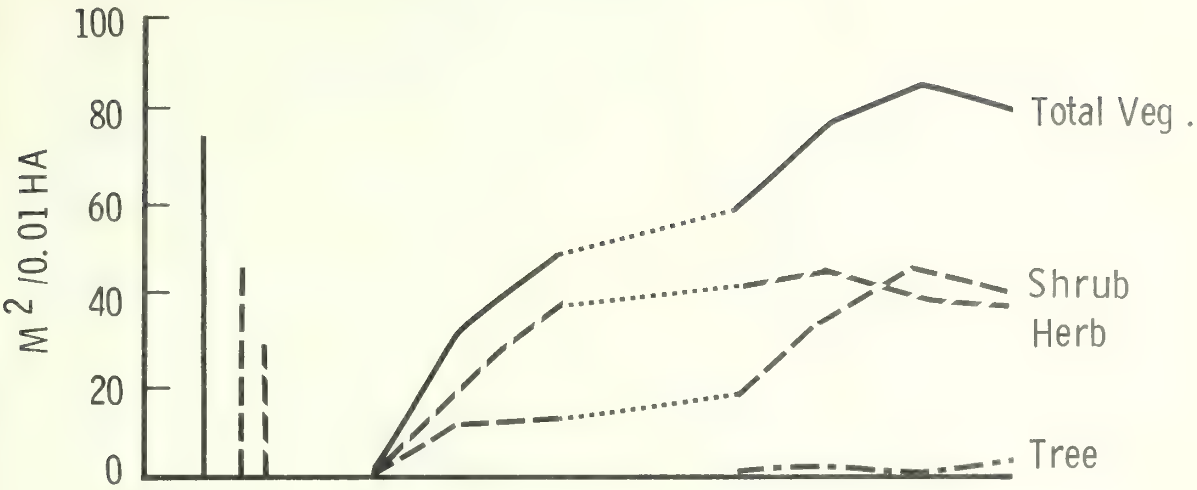


Figure 13-1. Vegetative cover.

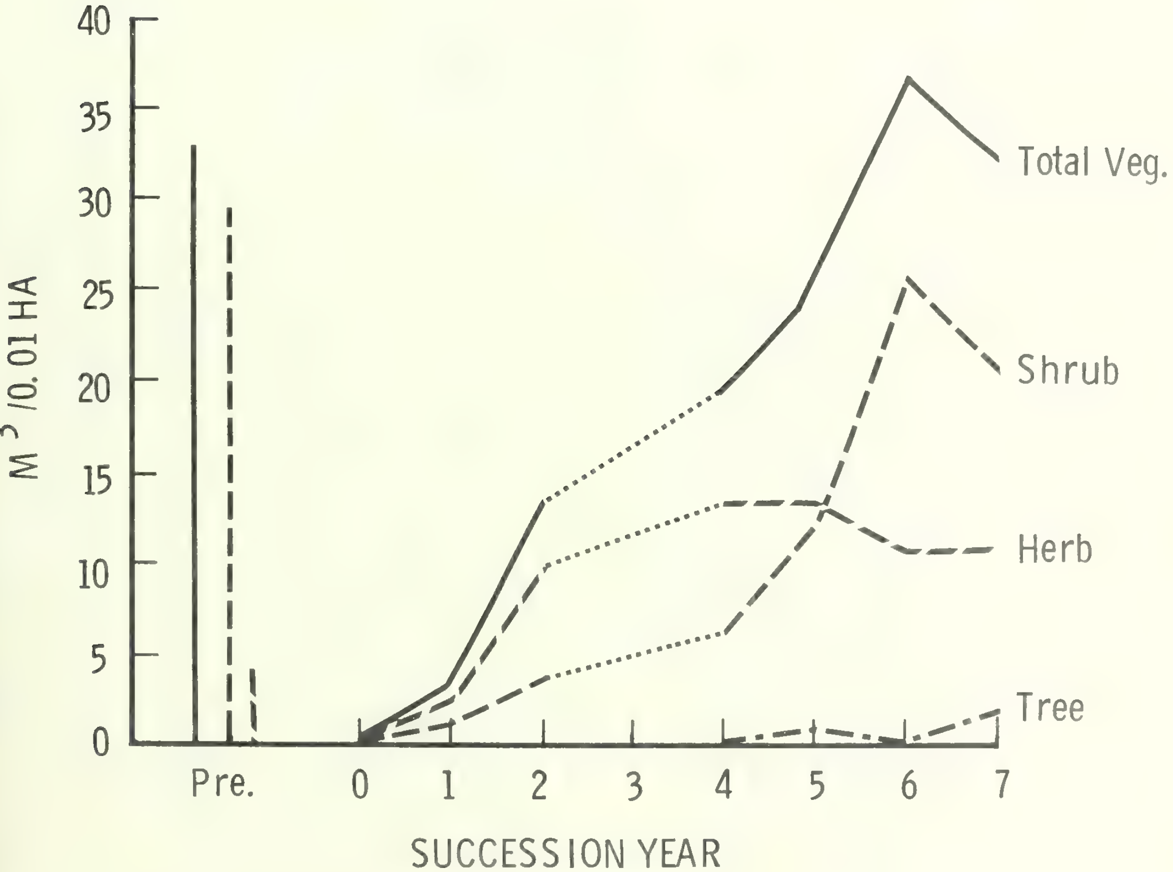


Figure 13-2. Vegetative volume.

Table 13-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 13-3.

Species	Succession year							
	Pre	1	2	3*	4	5	6	7
Acer glabrum	5	-	1		2	1	5	2
Amelanchier alnifolia	1	-	-		-	-	-	-
Ceanothus velutinus	-	8	3		2	8	11	12
Lonicera utahensis	1	-	-		-	-	-	-
Pachistima myrsinites	-	-	-		-	-	-	2
Ribes viscosissimum	2	-	-		2	3	6	6
Rosa gymnocarpa	-	-	-		-	1	-	-
Rubus parviflorus	10	1	2		1	3	3	3
Salix scouleriana	-	-	-		-	<1	-	<1
Spiraea betulifolia	1	2	3		6	8	8	6
Vaccinium globulare	25	1	2		6	9	13	9
Total shrubs	45	11	12		17	34	46	40

Table 13-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 13-4.

Species	Succession year							
	Pre	1	2	3*	4	5	6	7
Anaphalis margaritaceae	-	-	-		-	-	1	1
Anemone piperi	2	2	5		7	7	4	1
Arenaria macrophylla	-	2	4		2	4	2	1
Calamagrostis rubescens	3	2	2		2	7	5	6
Carex concinnoides	-	-	-		-	-	1	2
Carex geyeri	3	-	-		-	-	-	1
Carex rossii	-	-	2		6	6	8	6
Chimaphila umbellata	1	-	-		-	-	-	-
Clintonia uniflora	2	-	-		-	-	-	-
Coptis occidentalis	2	-	-		-	-	-	-
Epilobium angustifolium	-	2	7		13	10	8	8
Epilobium paniculatum	-	-	1		-	-	-	-
Epilobium watsonii	-	-	2		-	-	-	-
Geranium bicknellii	-	1	-		-	-	-	-
Gnaphalium microcephalum	-	-	2		-	-	-	-
Hieracium albiflorum	-	-	-		-	-	2	2
Pteridium aquilinum	-	1	2		2	3	1	2
Thalictrum occidentale	1	-	-		-	-	-	-
Xerophyllum tenax	8	-	1		-	-	2	-
Misc. herbs	7	10	8		9	8	8	6
Total herbs	29	20	37		41	44	39	37

*No data taken

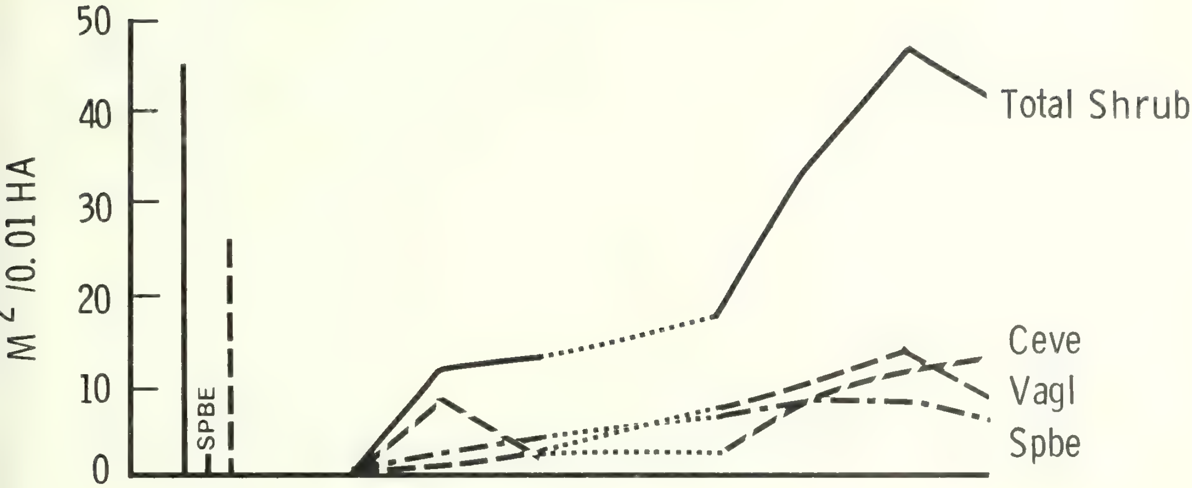


Figure 13-3. Shrub cover.

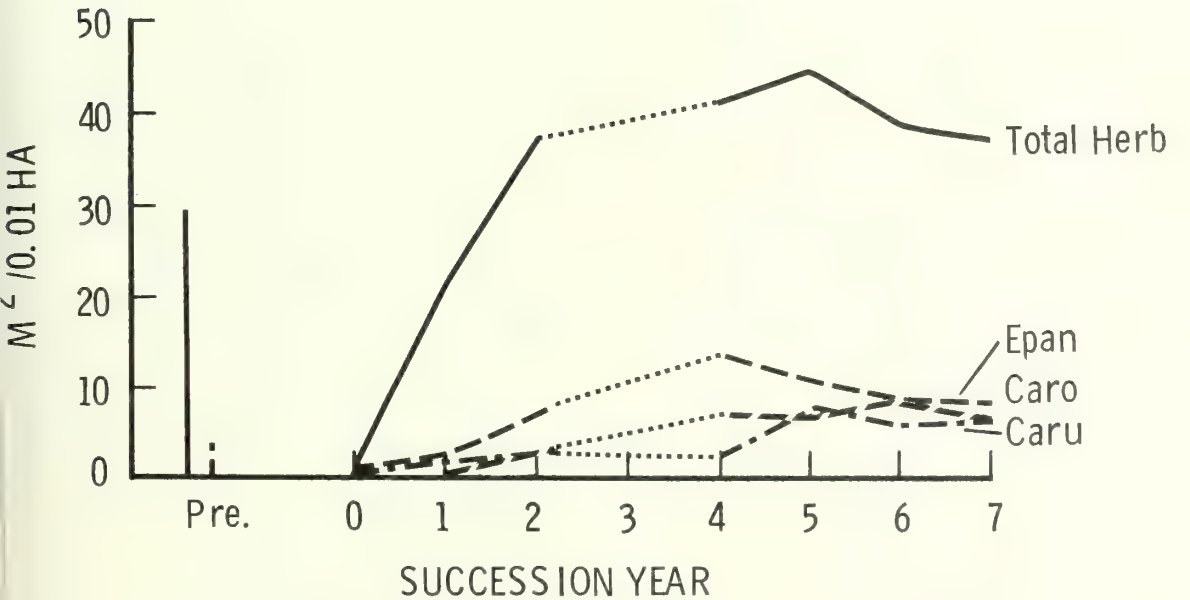


Figure 13-4. Herb cover.

NR: E-3 (A-27)

Table 13-5.--Volume development of shrub component (m^3/0.01 ha), fig. 13-5.

Species	Succession year							
	Pre	1	2	3*	4	5	6	7
Acer glabrum	10.8	-	1.0		1.6	1.1	6.3	2.1
Amelanchier alnifolia	.1	-	-		-	-	-	-
Ceanothus velutinus	-	0.4	.3		.4	2.6	6.9	7.8
Lonicera utahensis	.4	-	-		-	-	-	-
Pachistima myrsinites	-	-	-		-	-	-	.5
Ribes viscosissimum	1.4	-	-		.6	1.5	3.9	3.1
Rosa gymnocarpa	-	-	-		-	.4	-	-
Rubus parviflorus	3.3	.1	.8		.2	1.2	1.6	1.1
Salix scouleriana	-	-	-		-	.1	-	.6
Spiraea betulifolia	.2	.3	.8		2.1	2.6	3.1	1.9
Vaccinium globulare	12.8	.2	.6		1.5	2.4	3.2	2.8
Total shrubs	29.0	1.0	3.5		6.2	12.0	25.1	19.8

Table 13-6.--Volume development of herb component (m^3/0.01 ha), fig. 13-6.

Species	Succession year							
	Pre	1	2	3*	4	5	6	7
Anaphalis margaritaceae	-	-	-		-	-	0.2	0.2
Anemone piperi	0.2	0.1	0.5		1.0	0.8	.4	.1
Arenaria macrophylla	-	.1	.2		.1	.2	.1	<.1
Calamagrostis rubescens	.3	.2	.8		.3	1.8	1.1	1.3
Carex concinnoides	-	-	-		-	-	.1	.2
Carex geyeri	.3	-	-		-	-	-	.2
Carex rossii	-	-	.3		1.0	1.1	1.2	.9
Chimaphila umbellata	.1	-	-		-	-	-	-
Clintonia uniflora	.1	-	-		-	-	-	-
Coptis occidentalis	.2	-	-		-	-	-	-
Epilobium angustifolium	-	.6	3.0		7.9	6.3	5.0	4.9
Epilobium paniculatum	-	-	.4		-	-	-	-
Epilobium watsonii	-	-	.8		-	-	-	-
Geranium bicknellii	-	.1	-		-	-	-	-
Gnaphalium microcephalum	-	-	1.7		-	-	-	-
Hieracium albiflorum	-	-	-		-	-	.2	.5
Pteridium aquilinum	-	.2	.5		.6	1.3	.3	1.0
Thalictrum occidentale	.3	-	-		-	-	-	-
Xerophyllum tenax	1.4	-	.2		-	-	.3	-
Misc. herbs	.9	1.0	1.4		1.9	1.4	1.6	1.2
Total herbs	3.8	2.2	9.7		12.8	12.9	10.7	10.6

*No data taken

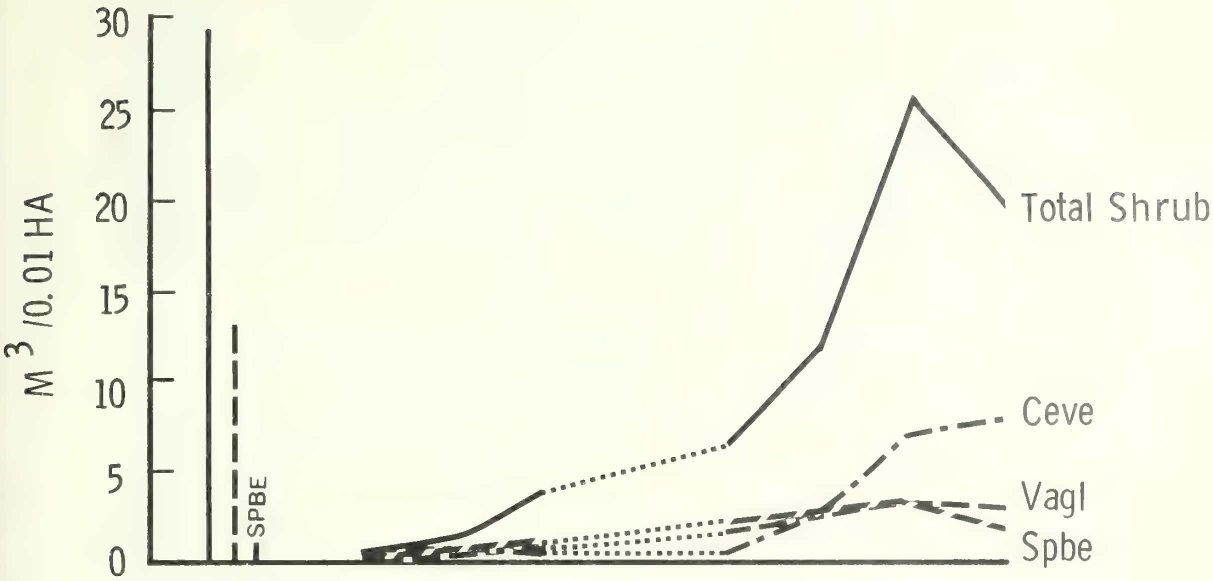


Figure 13-5. Shrub volume.

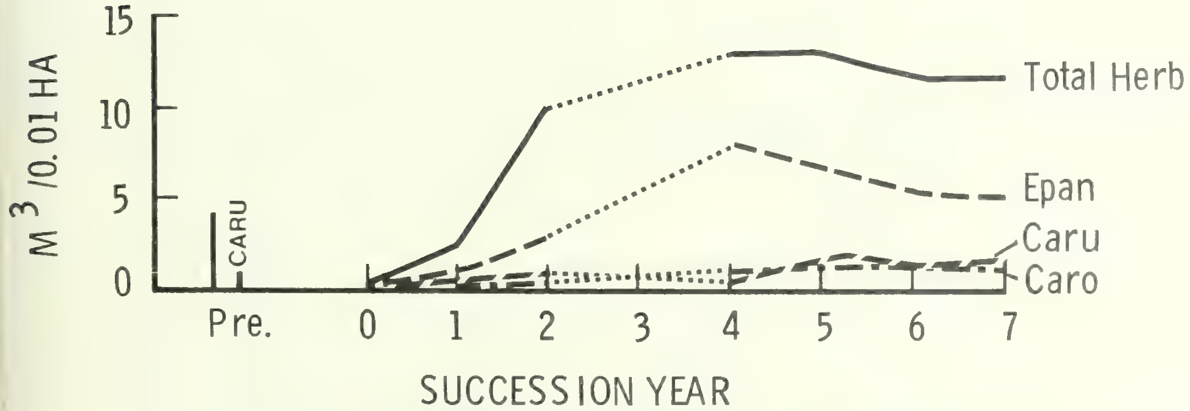


Figure 13-6. Herb volume.

NEWMAN RIDGE: South-2 (1802-13 Area 24)

Site location and description: SE¼SW¼ Sec. 26, T18N R29W MPM.
Elevation: 5,100 ft; Exposure: Southeast (Az. 131°); Slope: 35%
Habitat type: Abies grandis/Clintonia uniflora, Xerophyllum tenax Phase
Predisturbance forest stand: Pico 62%, Laoc 28%, Psme 9%, Abgr 1%, Abla 1% (Stand basal area: 4,065 cm^2/0.01 ha)
Disturbance treatment: Logged September 1968; Slashed November 1968;
Broadcast-burned: July 16, 1969 (Succession year 1:1970)
Fire intensity: 813 g water loss; Duff moisture: Upper 43%, Lower 73%; Postfire duff depth: 1.9 cm (43% of preburn)

Table 14-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 14-1.

Life-form component	Succession year							
	Pre	1	2	3	4	5	6	7
Tree	-	-	-	-	-	-	-	-
Shrub	62	17	26	28	31	52	67	86
Herb	53	19	35	42	37	39	44	37
Total veg.	115	36	61	70	69	91	111	124
Exposed ground surface:								
Bare ground	-	15	7	3	4	2	4	3
Rock	-	-	1	-	-	-	-	-
Litter	19	35	27	23	19	12	5	14
Moss	-	14	6	5	12	7	7	9

Table 14-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 14-2.

Life-form component	Succession year							
	Pre	1	2	3	4	5	6	7
Tree	-	-	-	-	-	-	-	-
Shrub	32.6	8.8	7.0	6.8	8.5	17.6	31.2	61.1
Herb	10.6	2.5	8.6	8.9	9.9	9.8	12.5	10.4
Total veg.	43.3	11.3	15.6	15.7	18.4	27.5	43.7	71.5

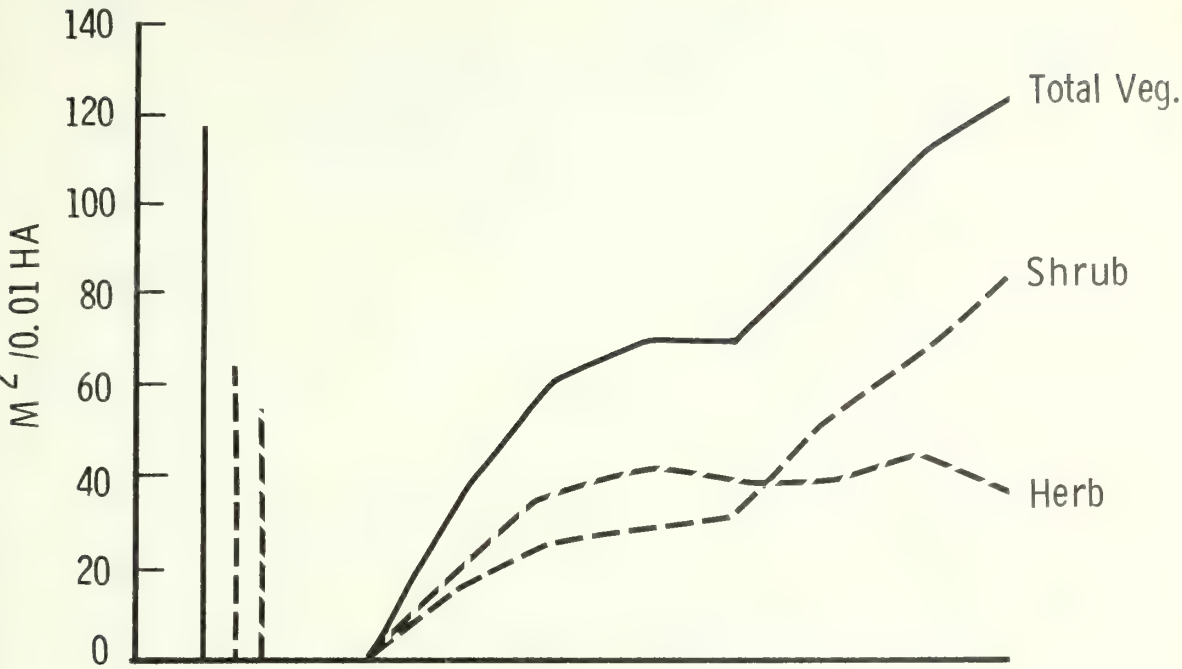


Figure 14-1. Vegetative cover.

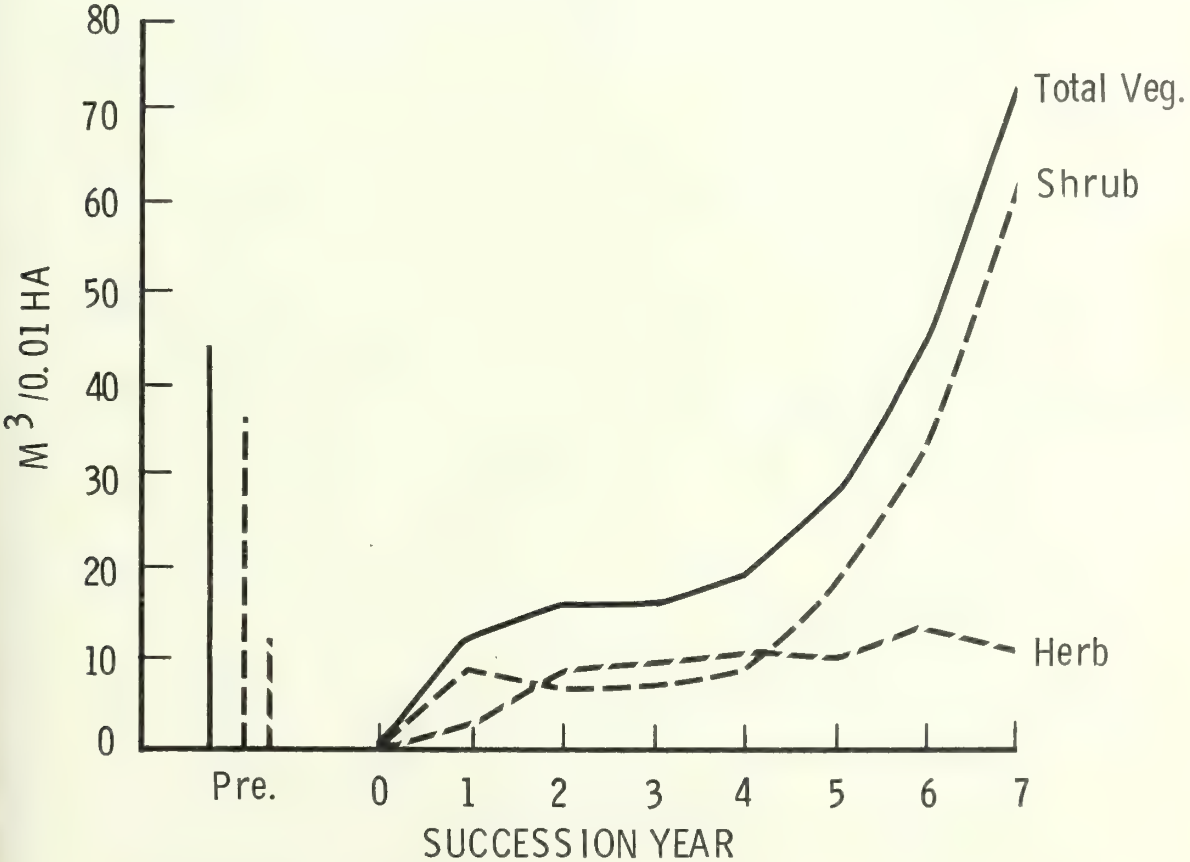


Figure 14-2. Vegetative volume.

Table 14-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 14-3.

Species	Succession year							
	Pre	1	2	3	4	5	6	7
Ceanothus velutinus	-	9	2	-	2	11	22	46
Rosa gymnocarpa	2	1	2	2	3	5	5	3
Salix scouleriana	-	-	-	<1	1	2	2	4
Spiraea betulifolia	1	4	11	8	6	7	11	5
Vaccinium globulare	59	2	11	18	19	27	27	28
Total shrubs	62	17	26	28	31	52	67	86

Table 14-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 14-4.

Species	Succession year							
	Pre	1	2	3	4	5	6	7
Anemone piperi	-	2	6	7	4	1	2	-
Arenaria macrophylla	-	-	1	-	-	-	-	-
Calamagrostis rubescens	2	2	3	4	5	11	11	8
Carex concinnoides	-	-	-	1	-	-	-	2
Carex geyeri	-	-	-	-	-	-	-	1
Carex rossii	-	-	2	3	2	4	5	4
Clintonia uniflora	1	-	-	-	-	-	-	-
Coptis occidentalis	2	-	-	-	-	-	-	-
Epilobium angustifolium	-	1	2	6	5	4	6	4
Hieracium albiflorum	1	-	-	-	-	-	-	-
Pteridium aquilinum	-	-	2	-	1	-	2	-
Xerophyllum tenax	36	7	10	12	12	13	13	16
Misc. herbs	12	8	9	9	8	6	5	2
Total herbs	53	19	35	42	37	39	44	37

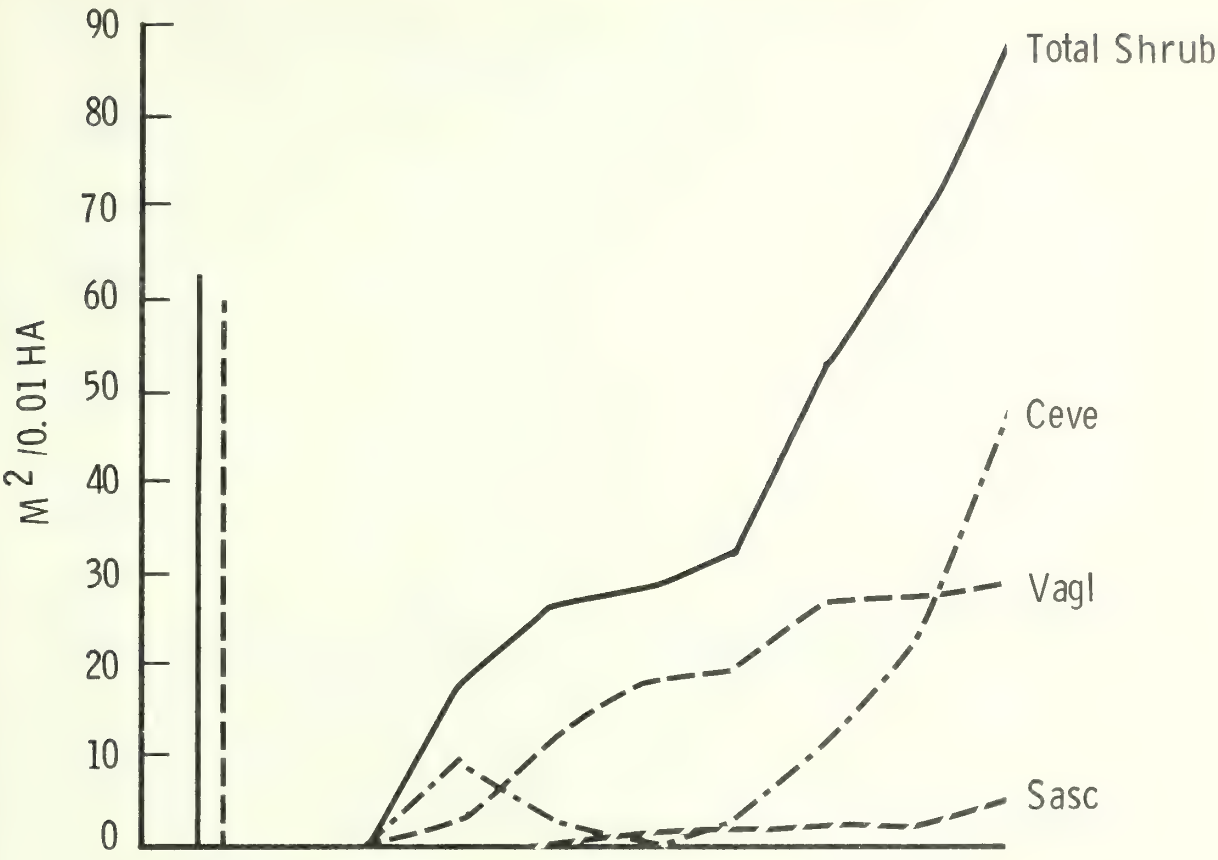


Figure 14-3. Shrub cover.

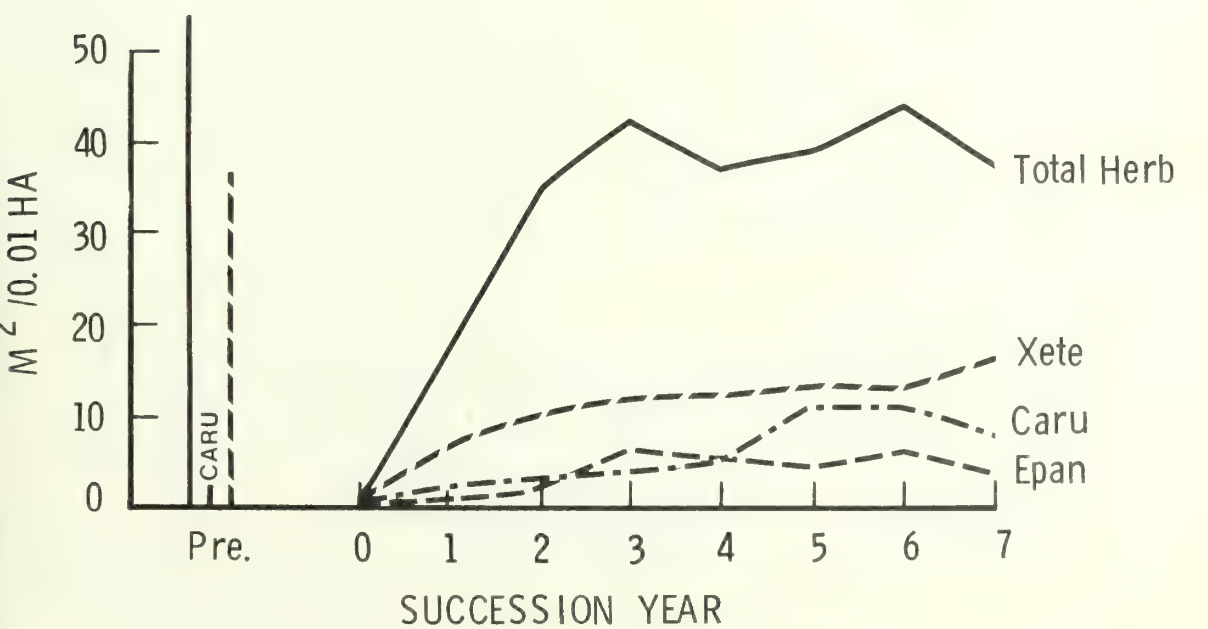


Figure 14-4. Herb cover.

NR: S-2 (A-24)

Table 14-5.--Volume development of shrub component (m^3/0.01 ha), fig. 14-5.

Species	Succession year							
	Pre	1	2	3	4	5	6	7
Ceanothus velutinus	-	4.6	0.1	-	1.0	6.0	17.3	46.8
Rosa gymnocarpa	1.2	.2	.4	0.5	1.0	1.8	2.2	1.0
Salix scouleriana	-	-	-	<.1	.6	1.3	1.7	4.4
Spiraea betulifolia	.2	.7	4.4	2.6	1.9	2.6	3.8	1.5
Vaccinium globulare	31.2	3.3	2.2	3.7	4.1	6.0	6.1	7.5
Total shrubs	32.6	8.8	7.0	6.8	8.5	17.6	31.2	61.1

Table 14-6.--Volume development of herb component (m^3/0.01 ha), fig. 14-6.

Species	Succession year							
	Pre	1	2	3	4	5	6	7
Anemone piperi	-	0.1	0.5	0.9	0.7	0.1	0.3	-
Arenaria macrophylla	-	-	<.1	-	-	-	-	-
Calamagrostis rubescens	0.2	.3	2.4	1.0	1.1	2.8	2.9	2.2
Carex concinnoides	-	-	-	.1	-	-	-	.3
Carex geyeri	-	-	-	-	-	-	-	.2
Carex rossii	-	-	.3	.5	.3	.6	.9	.5
Clintonia uniflora	.1	-	-	-	-	-	-	-
Coptis occidentalis	.4	-	-	-	-	-	-	-
Epilobium angustifolium	-	.1	.8	2.2	3.2	2.4	3.4	2.2
Hieracium albiflorum	<.1	-	-	-	-	-	-	-
Pteridium aquilinum	-	-	.6	-	.3	-	.8	-
Xerophyllum tenax	8.6	1.3	2.6	2.6	3.0	3.1	3.5	4.7
Misc. herbs	1.3	.7	1.4	1.7	1.4	.9	.7	.3
Total herbs	10.6	2.5	8.6	8.9	9.9	9.8	12.5	10.4

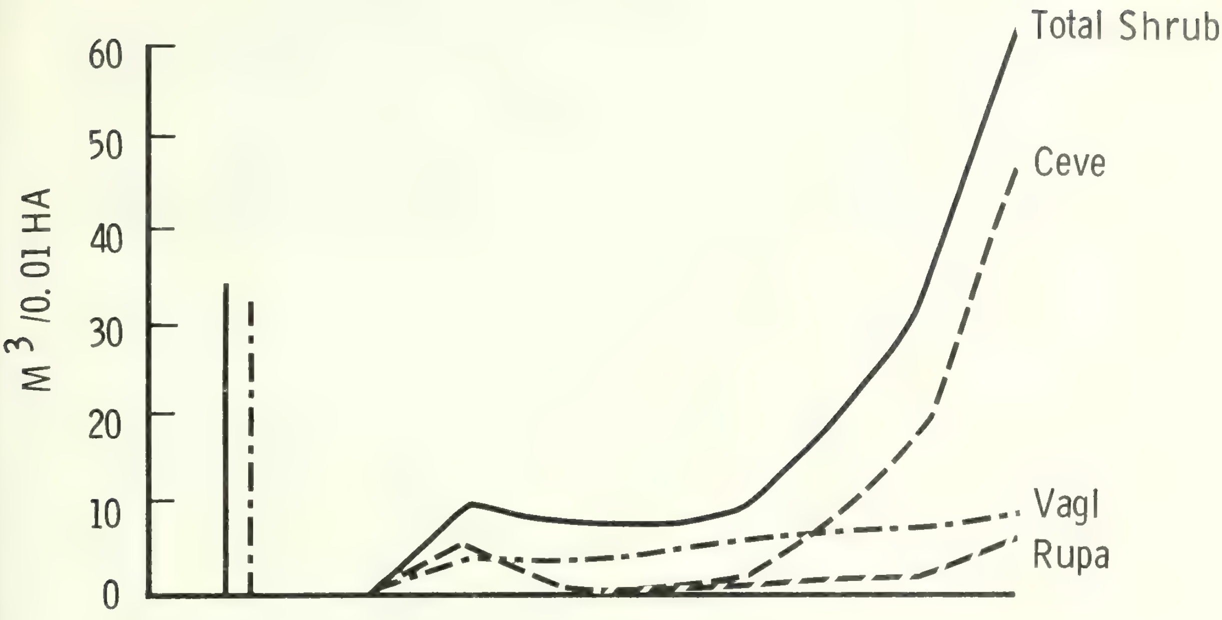


Figure 14-5. Shrub volume.

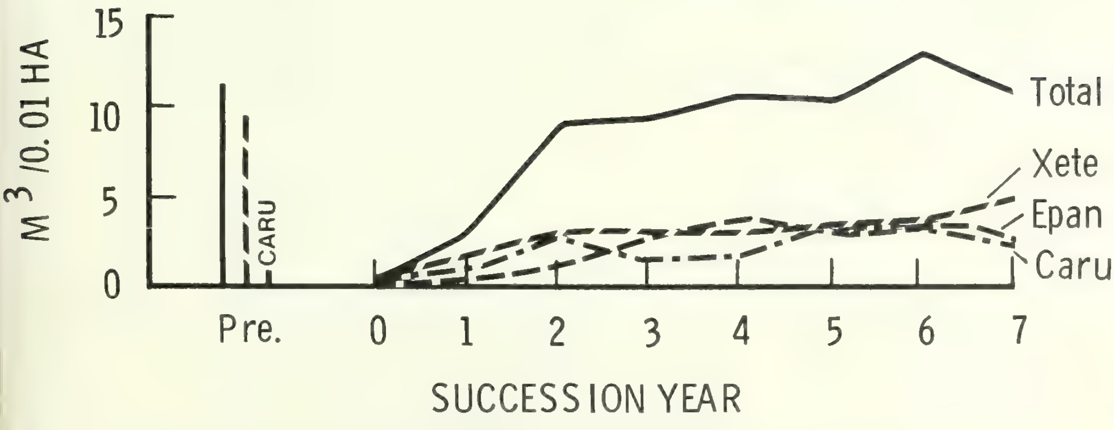


Figure 14-6. Herb volume.

NEWMAN RIDGE: South-3 (1802-13 Area 28)

Site location and description: SE¼NE¼ Sec. 34, T18N R29W MPM.
Elevation: 5,200 ft; Exposure: South (Az. 166°); Slope: 50%
Habitat type: Pseudotsuga menziesii/Vaccinium globulare, Xerophyllum tenax Phase
Predisturbance forest stand: Pico 55%, Laoc 27%, Pimo 10%, Psme 7% (Stand basal area: 4,863 cm^2/0.01 ha)
Disturbance treatment: Logged June 1969; Slashed June 1969;
Broadcast-burned: September 15, 1970 (Succession year 1:1971)
Fire intensity: 1,976 g water loss; Duff moisture: Upper --%, Lower --%; Postfire duff depth: 0.3 cm (8% of preburn depth)

Table 15-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 15-1.

Life-form component	Succession year						
	Pre	1**	2*	3	4	5	6
Tree	-	-		-	-	-	-
Shrub	74	14		23	47	57	62
Herb	47	15		26	42	36	38
Total veg.	122	29		49	89	93	10
Exposed ground surface:							
Bare ground	-	49		22	3	8	1
Rock	-	3		12	2	5	4
Litter	30	19		18	10	15	17
Moss	-	-		2	3	6	11

Table 15-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 15-2.

Life-form component	Succession year						
	Pre	1**	2*	3	4	5	6
Tree	-	-		-	-	-	-
Shrub	41.2	1.2		6.1	17.6	25.2	31.7
Herb	8.4	4.7		5.8	10.4	7.3	7.8
Total veg.	49.6	5.9		11.9	28.0	32.6	39.5

*No data taken.

**T-2 80% destroyed by bulldozer fire line construction; data adjusted on basis of 6 out of 10 sample blocks receiving clearcut and broadcast burn treatment. T-2 relocated to adjacent site within treated area for SY-3 and all subsequent years.

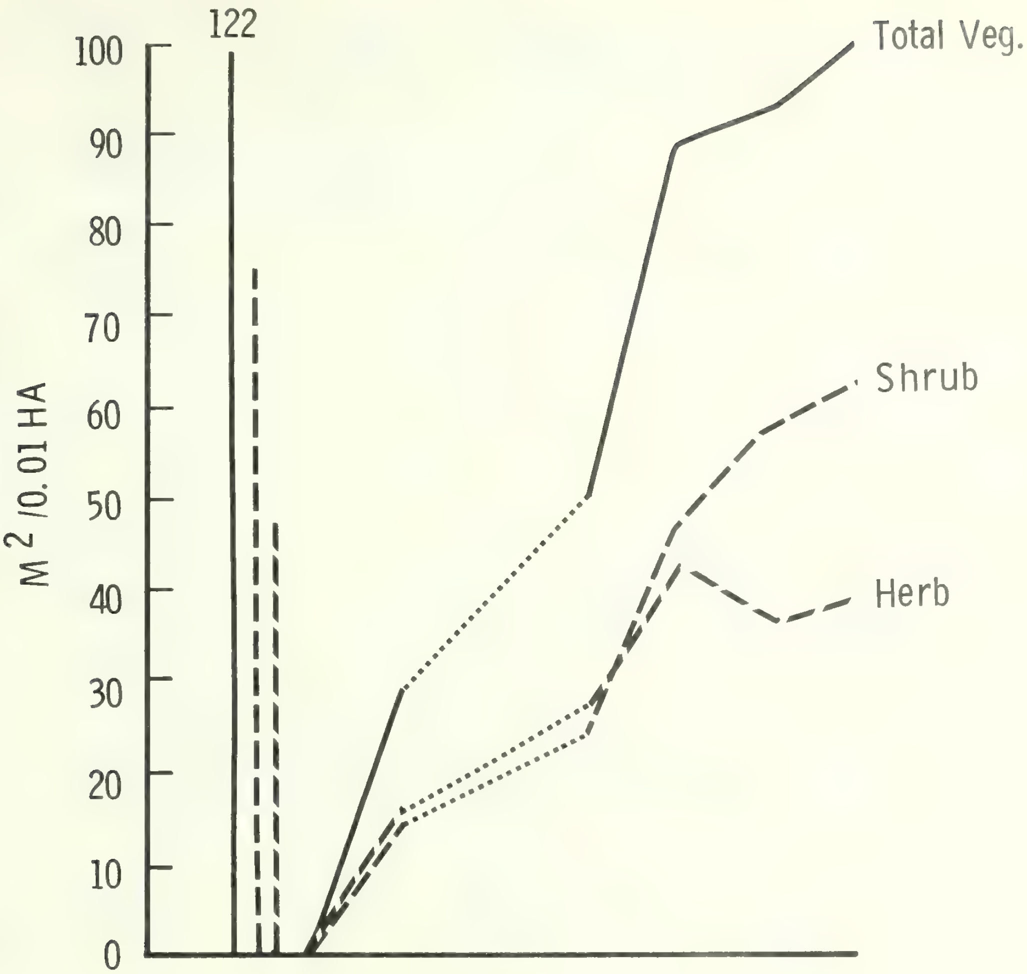


Figure 15-1. Vegetative cover.

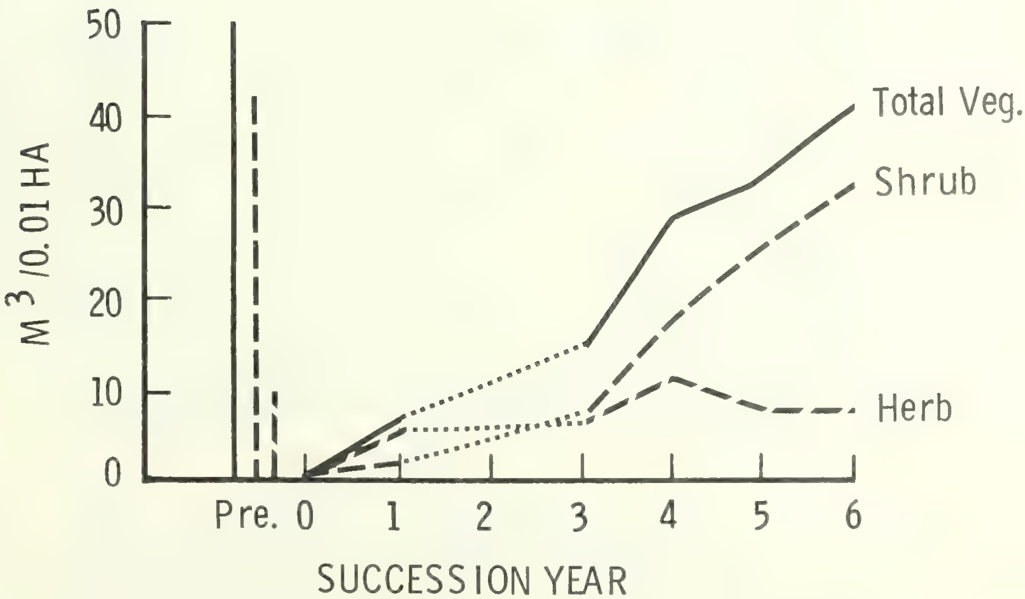


Figure 15-2. Vegetative volume.

NR: S-3 (A-28)

Table 15-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 15-3.

Species	Succession year						
	Pre	1**	2*	3	4	5	6
Amelanchier alnifolia	<1	-		-	-	-	-
Ceanothus velutinus	-	11		6	25	32	41
Rosa gymnocarpa	11	-		4	2	6	3
Rubus parviflorus	3	-		-	-	-	-
Spiraea betulifolia	2	3		13	19	16	14
Vaccinium globulare	57	-		1	1	3	3
Total shrubs	74	14		23	47	57	62

Table 15-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 15-4.

Species	Succession year						
	Pre	1**	2*	3	4	5	6
Anemone piperi	-	-		-	-	2	1
Arenaria macrophylla	-	1		-	1	-	-
Berberis repens	1	1		2	2	2	2
Calamagrostis rubescens	12	4		9	18	13	16
Carex rossii	-	-		2	4	2	6
Epilobium angustifolium	-	-		1	1	1	-
Epilobium paniculatum	-	-		2	3	-	-
Xerophyllum tenax	19	3		6	7	9	9
Misc. herbs	16	6		5	5	7	5
Total herbs	47	15		26	42	36	38

*No data taken.

**T-2 80% destroyed by bulldozer fire line construction; data adjusted on basis of 6 out of 10 sample blocks receiving clearcut and broadcast burn treatment. T-2 relocated to adjacent site within treated area for SY=3 and all subsequent years.

NR: S-3 (A-28)

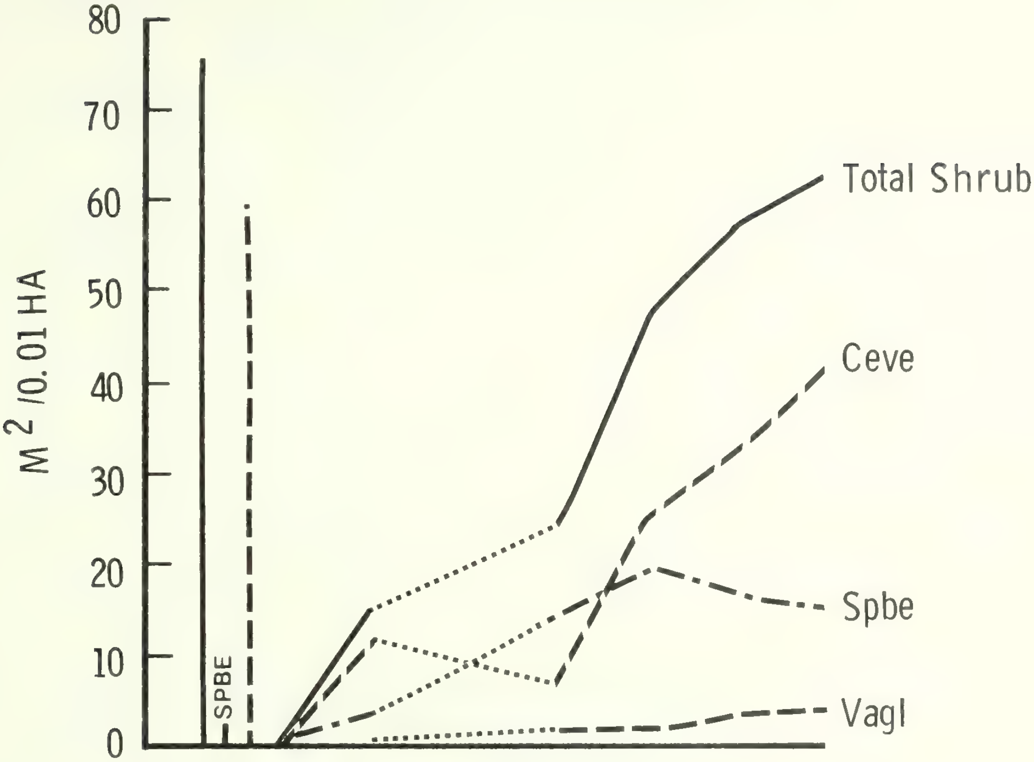


Figure 15-3. Shrub cover.

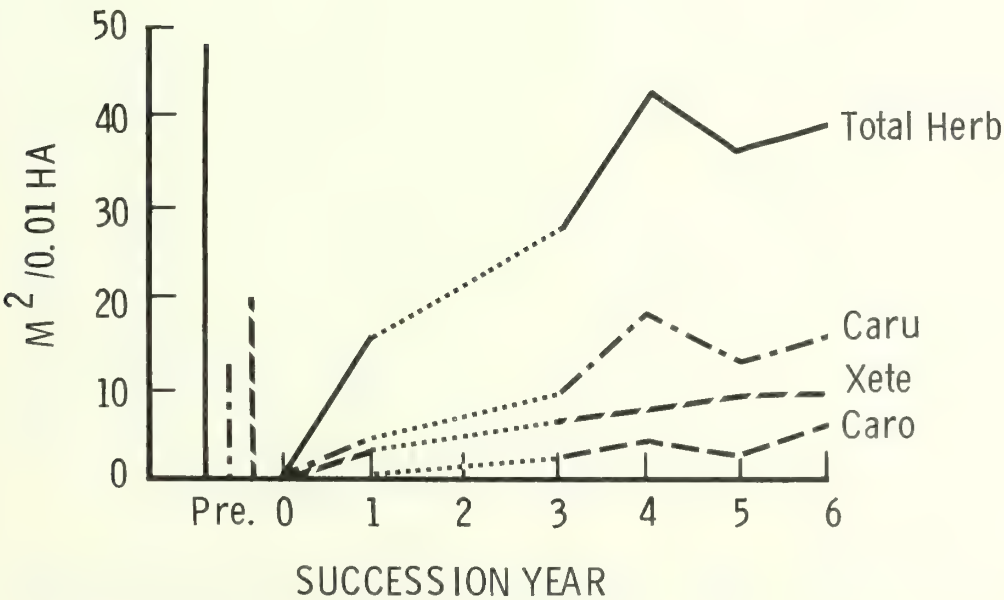


Figure 15-4. Herb cover.

NR: S-3 (A-28)

Table 15-5.--Volume development of shrub component (m^3/0.01 ha), fig. 15-5.

Species	Succession year						
	Pre	1**	2*	3	4	5	6
Amelanchier alnifolia	0.1	-		-	-	-	-
Ceanothus velutinus	-	0.6		1.2	10.4	18.0	26.4
Rosa gymnocarpa	7.1	-		1.3	1.4	2.3	.8
Rubus parviflorus	1.0	-		-	-	-	-
Spiraea betulifolia	.7	.6		3.5	5.7	4.4	4.0
Vaccinium globulare	32.6	-		.1	.1	.4	.5
Total shrubs	41.2	1.2		6.1	17.6	25.2	31.7

Table 15-6.--Volume development of herb component (m^3/0.01 ha), fig. 15-6.

Species	Succession year						
	Pre	1**	2*	3	4	5	6
Anemone piperi	-	-		-	-	0.2	0.1
Arenaria macrophylla	-	0.1		-	<0.1	-	-
Berberis repens	0.1	.2		0.3	.5	.2	.3
Calamagrostis rubescens	1.1	3.0		2.4	5.9	3.0	4.0
Carex rossii	-	-		.2	.6	.4	.8
Epilobium angustifolium	-	-		.3	.4	.6	-
Epilobium paniculatum	-	-		.6	.8	-	-
Xerophyllum tenax	5.1	.3		1.0	1.4	1.8	1.9
Misc. herbs	2.0	1.2		.9	.8	1.1	.8
Total herbs	8.4	4.7		5.8	10.4	7.3	7.8

*No data taken.

**T-2 80% destroyed by bulldozer fire line construction; data adjusted on basis of 6 out of 10 sample blocks receiving clearcut and broadcast burn treatment. T-2 relocated to adjacent site within treated area for SY-3 and all subsequent years.

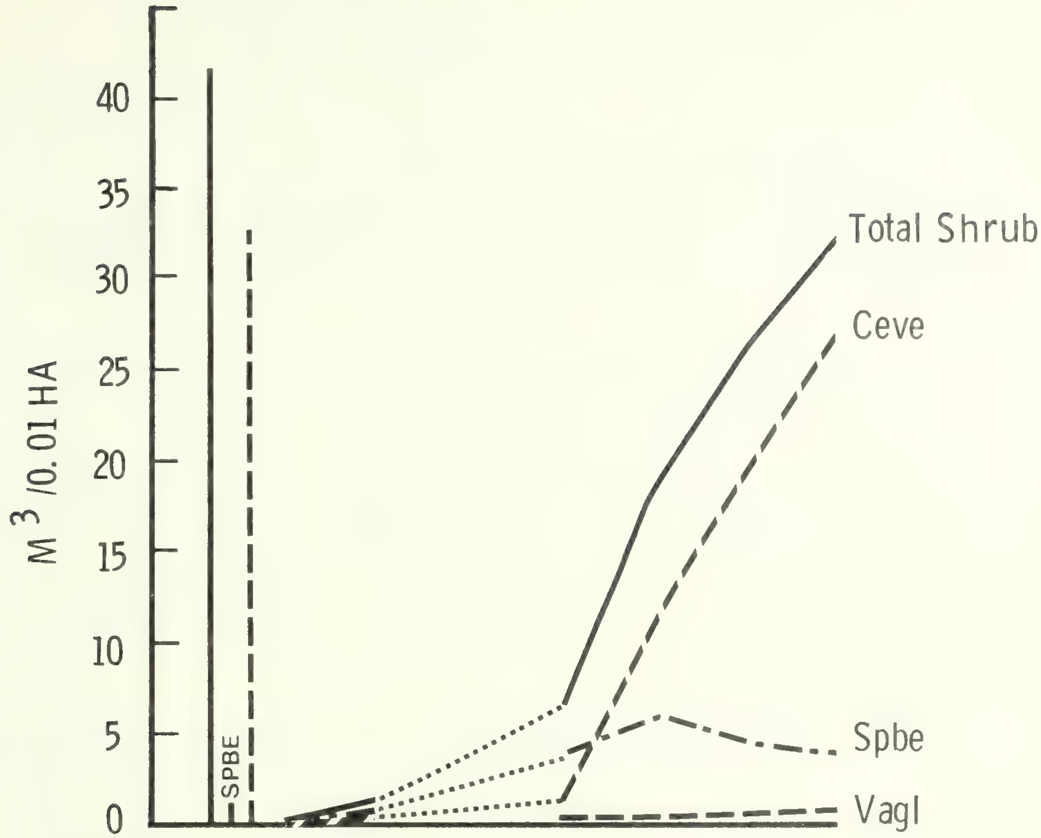


Figure 15-5. Shrub volume.

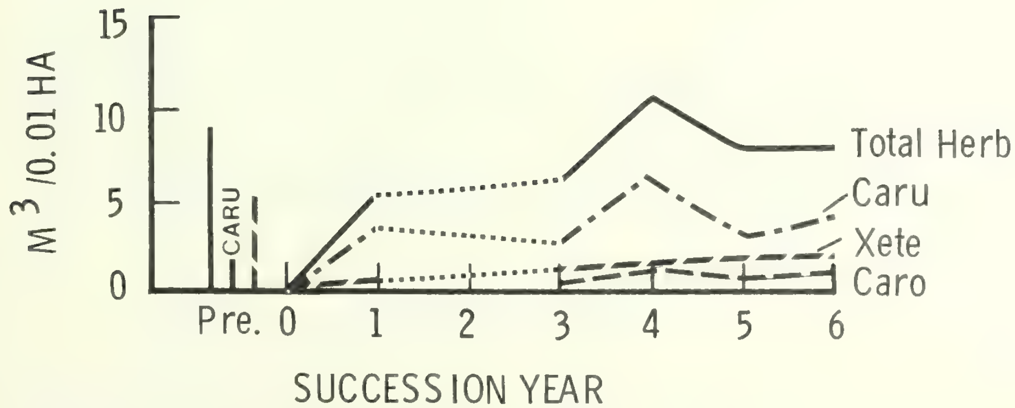


Figure 15-6. Herb volume.

NEWMAN RIDGE: West-2 (1802-13 Area 25)

Site location and description: NW¼SW¼ Sec. 25, T18N R29W MPM.
Elevation 4,900 ft; Exposure: West; Slope: 55%
Habitat type: Abies grandis/Clintonia uniflora, Xerophyllum tenax Phase
Predisturbance forest stand: Abgr 74%, Pico 23%, Psme 4%
(Stand basal area: 3,308 cm^2/0.01 ha)
Disturbance treatment: Logged September 1968; Slashed November 1968;
Broadcast-burned: July 18, 1969 (Succession year 1:1970)
Fire intensity: 1,253 g water loss; Duff moisture: Upper 20%, Lower 40%; Postfire duff depth: 2.2 cm (41% of preburn depth)

Table 16-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 16-1.

Life-form component	Succession year							
	Pre	1	2	3	4	5	6	7
Tree	-	-	-	-	-	-	1	2
Shrub	49	10	19	19	22	37	47	32
Herb	44	19	53	44	42	44	45	35
Total veg.	93	29	72	63	63	81	93	69
Exposed ground surface:								
Bare ground	-	55	8	6	3	2	5	2
Rock	-	-	-	-	-	-	-	-
Litter	36	16	8	8	10	4	4	8
Moss	1	-	17	23	26	17	14	32

Table 16-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 16-2.

Life-form component	Succession year							
	Pre	1	2	3	4	5	6	7
Tree	-	-	-	-	-	-	0.3	1.9
Shrub	27.9	1.7	6.0	5.1	5.9	11.1	19.6	14.0
Herb	5.5	4.0	17.1	14.2	18.0	17.6	13.1	10.4
Total veg.	33.3	5.7	23.0	19.3	23.9	28.7	33.0	26.3

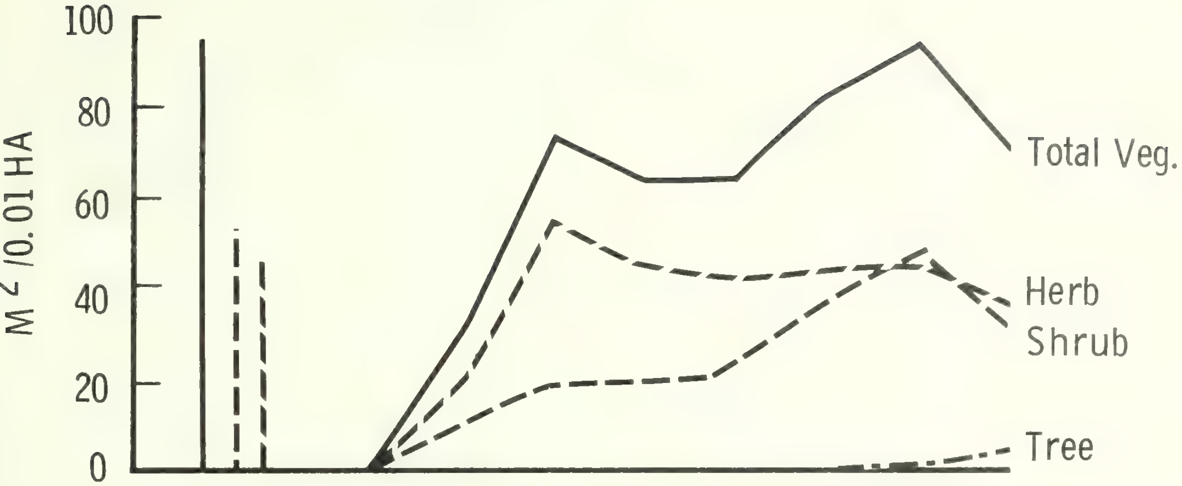


Figure 16-1. Vegetative cover.

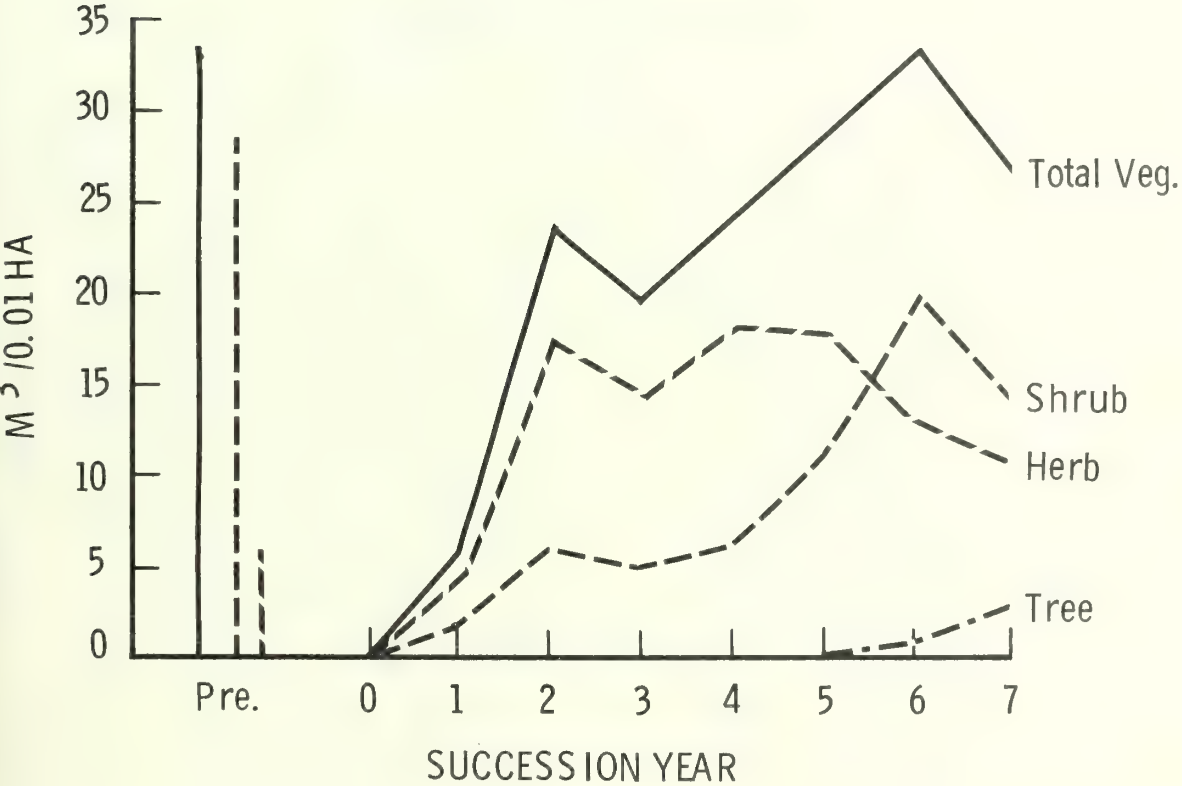


Figure 16-2. Vegetative volume.

NR: W-2 (A-25)

Table 16-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 16-3.

Species	Succession year							
	Pre	1	2	3	4	5	6	7
Ceanothus sanguineus	-	1	1	2	2	2	-	-
Pachistima myrsinites	<1	-	-	-	-	1	-	-
Ribes viscosissimum	-	-	1	-	1	2	2	2
Rosa gymnocarpa	2	-	-	-	-	1	1	<1
Salix scouleriana	-	-	-	<1	2	3	6	6
Spiraea betulifolia	5	8	13	9	8	16	21	12
Vaccinium globulare	42	2	4	8	9	12	17	12
Total shrubs	49	10	19	19	22	37	47	32

Table 16-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 16-4.

Species	Succession year							
	Pre	1	2	3	4	5	6	7
Adenocaulon bicolor	1	-	-	-	-	-	-	-
Anemone piperi	1	-	4	8	3	1	2	-
Calamagrostis rubescens	1	-	-	1	2	6	6	6
Carex concinnoides	-	-	-	2	2	3	4	7
Carex rossii	-	-	4	6	5	5	8	5
Clintonia uniflora	2	-	-	-	-	-	-	-
Coptis occidentalis	18	-	1	1	1	-	-	1
Epilobium angustifolium	-	12	22	17	20	23	15	9
Epilobium paniculatum	-	-	14	-	-	-	-	-
Epilobium watsonii	-	-	1	-	-	-	-	-
Thalictrum occidentale	1	-	-	-	-	-	-	-
Trillium ovatum	-	-	-	-	-	-	1	-
Xerophyllum tenax	10	-	-	1	1	-	1	1
Misc. herbs	11	8	8	9	8	6	8	7
Total herbs	44	19	53	44	42	44	45	35

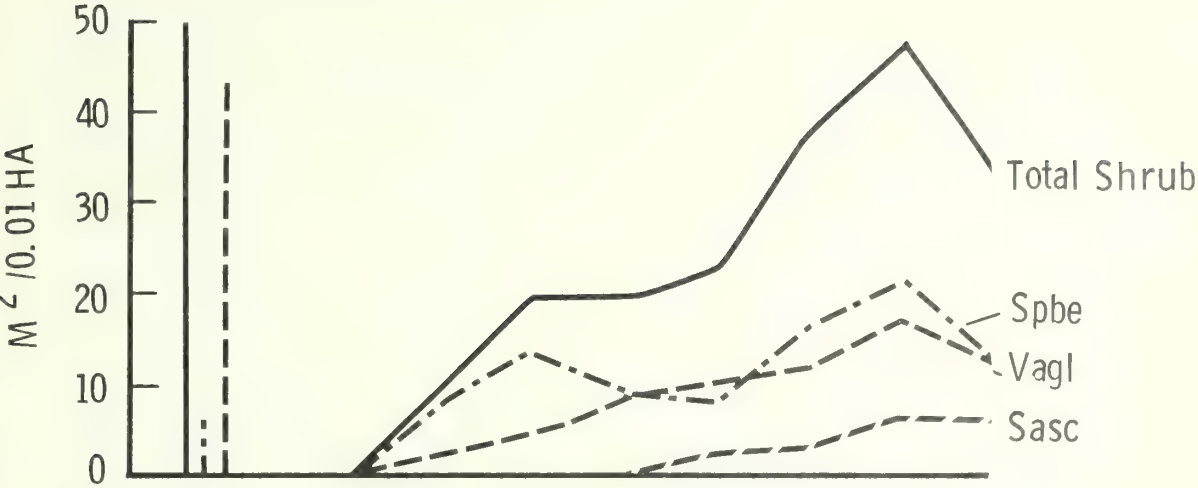


Figure 16-3. Shrub cover.

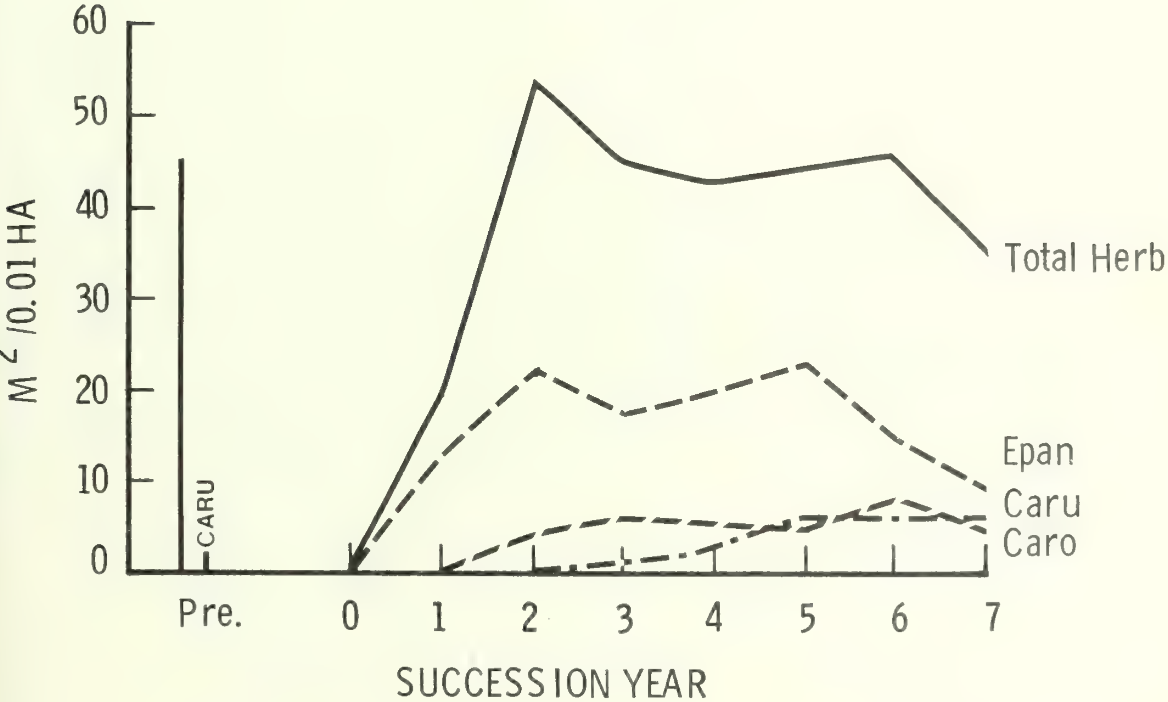


Figure 16-4. Herb cover.

Table 16-5.--Volume development of shrub component (m^3/0.01 ha), fig. 16-5.

Species	Succession year							
	Pre	1	2	3	4	5	6	7
Ceanothus sanguineus	-	0.1	0.1	0.3	0.3	0.3	-	-
Pachistima myrsinites	0.1	-	-	-	-	.1	-	-
Ribes viscosissimum	-	-	.1	-	.4	.8	1.4	1.6
Rosa gymnocarpa	1.1	-	-	-	-	.2	.4	.1
Salix scouleriana	-	-	-	.2	1.6	2.8	5.9	7.0
Spiraea betulifolia	1.2	1.4	5.0	3.0	2.2	4.5	8.0	2.9
Vaccinium globulare	25.4	.2	.7	1.6	1.4	2.4	4.0	2.5
Total shrubs	27.9	1.7	6.0	5.1	5.9	11.1	19.6	14.0

Table 16-6.--Volume development of herb component (m^3/0.01 ha), fig. 16-6.

Species	Succession year							
	Pre	1	2	3	4	5	6	7
Adenocaulon bicolor	0.2	-	-	-	-	-	-	-
Anemone piperi	.1	-	0.4	1.9	0.4	0.1	0.2	-
Calamagrostis rubescens	.1	-	-	.2	.4	1.3	1.6	2.2
Carex concinnoides	-	-	-	.2	.2	.3	.4	.8
Carex rossii	-	-	.6	.8	.6	.8	1.1	.8
Clintonia uniflora	.1	-	-	-	-	-	-	-
Coptis occidentalis	1.7	-	.1	<.1	.1	-	-	<.1
Epilobium angustifolium	-	3.4	11.2	9.7	15.0	14.4	8.3	5.2
Epilobium paniculatum	-	-	3.6	-	-	-	-	-
Epilobium watsonii	-	-	<.1	-	-	-	-	-
Thalictrum occidentale	.2	-	-	-	-	-	-	-
Trillium ovatum	-	-	-	-	-	-	.1	-
Xerophyllum tenax	2.0	-	-	.1	.1	-	.1	.1
Misc. herbs	1.1	.6	1.2	1.5	1.2	.7	1.3	1.2
Total herbs	5.5	4.0	17.1	14.2	18.0	17.6	13.1	10.4

NR: W-2 (A-25)

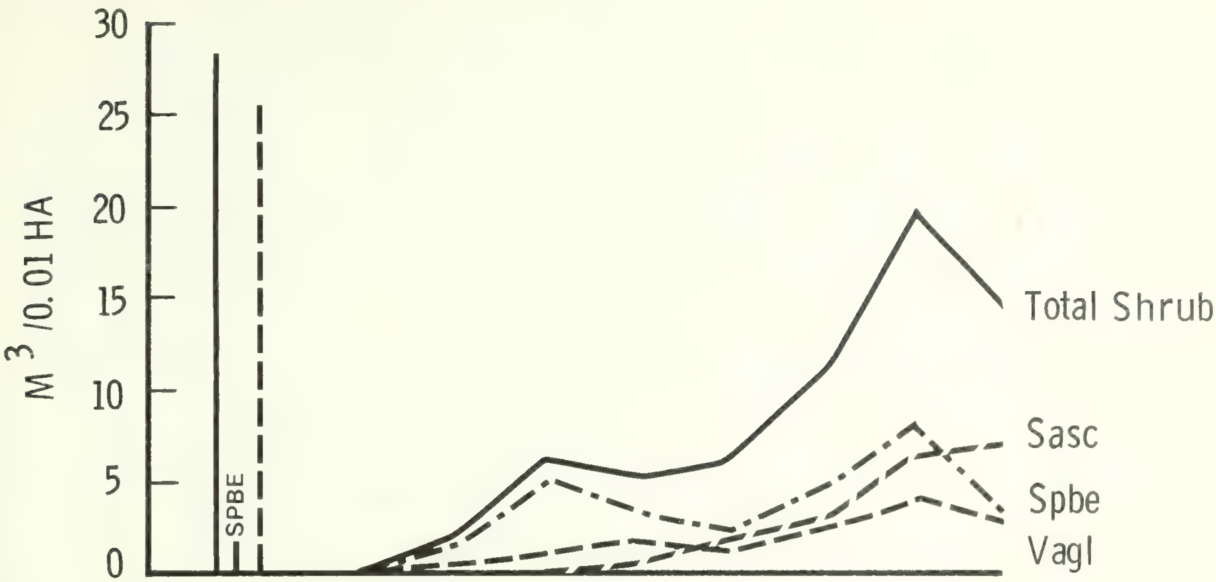


Figure 16-5. Shrub volume.

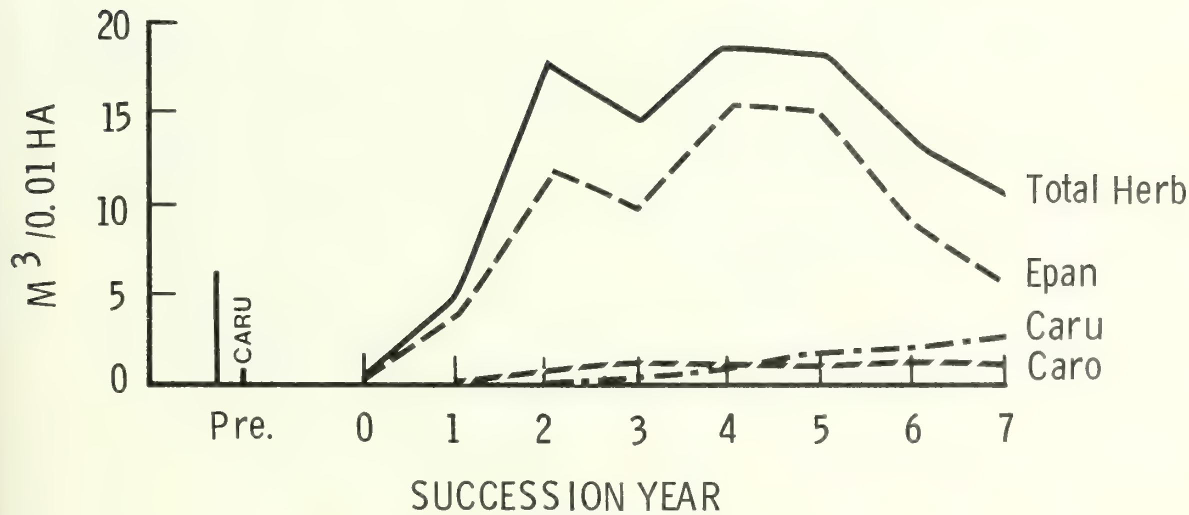


Figure 16-6. Herb volume.

NEWMAN RIDGE: West-3 (1802-13 Area 29)

Site location and description: SW¼SW¼ Sec. 26, T18N R29W MPM.
Elevation: 5,100 ft; Exposure: West (Az. 276°); Slope: 45%
Habitat type: Abies grandis/Clintonia uniflora, Xerophyllum tenax Phase
Predisturbance forest stand: Pico 35%, Psme 28%, Laoc 20%, Pimo 10%, Abla 7% (Stand basal area: 3,390 cm^2/0.01 ha)
Disturbance treatment: Logged November 1968; Slashed June 1969;
Broadcast-burned: September 28, 1970 (Succession year 1:1971)
Fire intensity: 283 g water loss; Duff moisture: Upper --%, Lower --%; Postfire duff depth: 1.0 cm (27% of preburn depth)

Table 17-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 17-1.

Life-form component	Succession year						
	Pre	1	2*	3	4	5	6
Tree	2	-		-	-	-	-
Shrub	54	7		19	37	44	51
Herb	42	10		27	36	35	31
Total veg.	98	17		46	73	79	82
Exposed ground surface:							
Bare ground	-	35		17	5	5	5
Rock	-	3		4	1	2	3
Litter	39	43		32	17	7	11
Moss	-	1		1	6	11	12

Table 17-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 17-2.

Life-form component	Succession year						
	Pre	1	2*	3	4	5	6
Tree	0.7	-		-	-	-	-
Shrub	29.8	1.1		3.2	8.6	12.0	18.9
Herb	8.0	1.5		5.5	7.2	6.8	6.3
Total veg.	38.5	2.6		8.7	15.8	18.8	25.2

* No data taken.

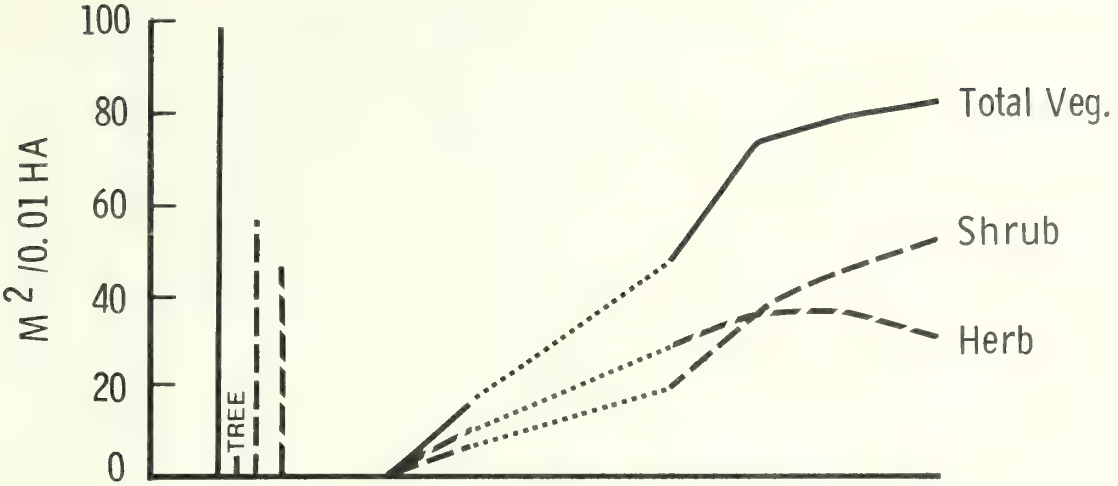


Figure 17-1. Vegetative cover.

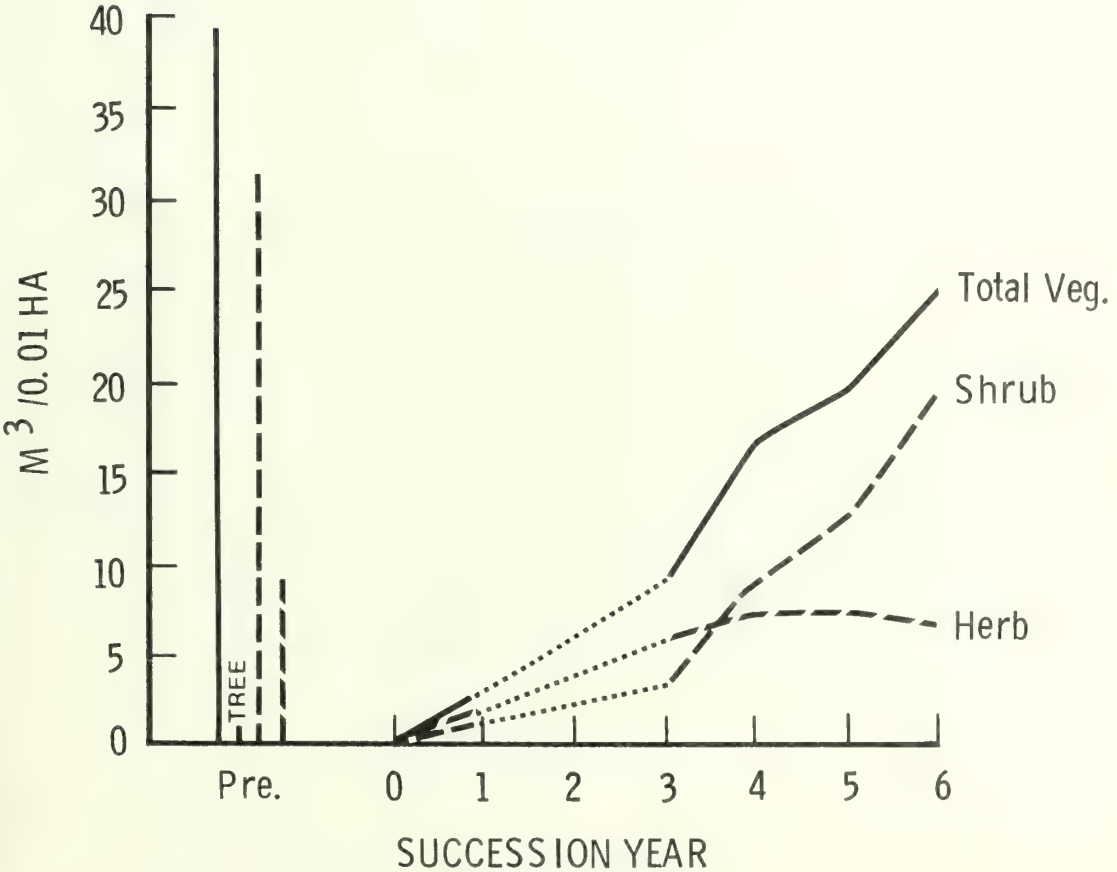


Figure 17-2. Vegetative volume.

Table 17-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 17-3.

Species	Succession year: Pre	1	2*	3	4	5	6
Acer glabrum	4	-		-	1	2	2
Amelanchier alnifolia	3	-		-	-	-	-
Ceanothus velutinus	-	3		7	13	15	24
Lonicera utahensis	1	-		-	-	1	1
Ribes viscosissimum	-	-		-	1	2	2
Rosa gymnocarpa	2	-		-	-	-	-
Spiraea betulifolia	1	4		11	17	18	16
Vaccinium globulare	44	-		2	5	7	7
Total shrubs	54	7		19	37	44	51

Table 17-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 17-4.

Species	Succession year: Pre	1	2*	3	4	5	6
Anemone piperi	-	-		-	-	1	-
Berberis repens	-	-		1	1	-	2
Calamagrostis rubescens	1	1		2	11	10	8
Calamagrostis tweedyi	-	1		2	5	4	3
Carex concinnoides	-	-		-	-	-	1
Carex rossii	-	-		6	8	9	8
Epilobium paniculatum	-	-		2	1	-	-
Xerophyllum tenax	32	3		4	3	7	5
Misc. herbs	9	5		10	7	4	2
Total herbs	42	10		27	36	35	31

*No data taken.

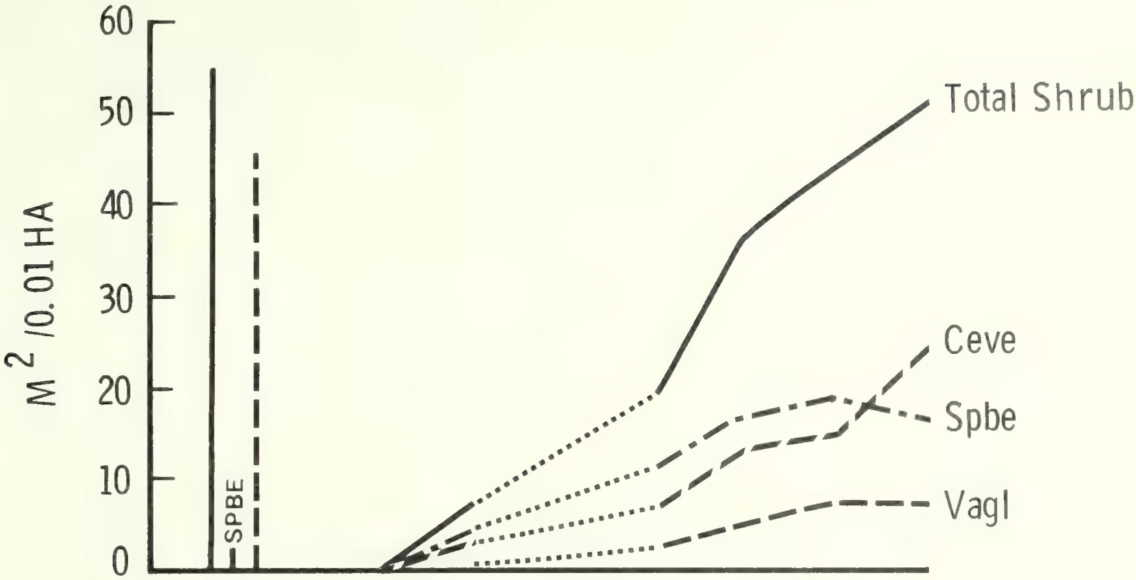


Figure 17-3. Shrub cover.

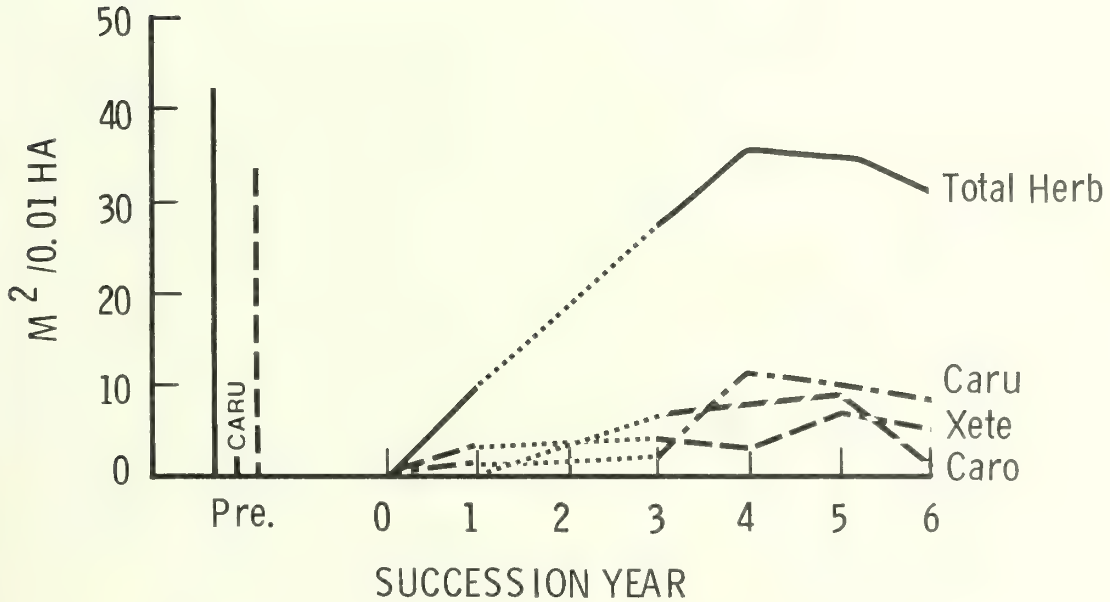


Figure 17-4. Herb cover.

Table 17-5.--Volume development of shrub component (m^3/0.01 ha), fig. 17-5.

Species	Succession year						
	Pre	1	2*	3	4	5	6
Acer glabrum	3.9	-		-	0.5	1.2	1.6
Amelanchier alnifolia	2.1	-		-	-	-	-
Ceanothus velutinus	-	0.2		0.5	2.0	3.0	10.7
Lonicera utahensis	.5	-		-	-	.5	.4
Ribes viscosissimum	-	-		-	.4	.7	.8
Rosa gymocarpa	1.6	-		-	-	-	-
Spiraea betulifolia	.2	1.0		2.5	4.8	5.7	4.2
Vaccinium globulare	21.6	-		.2	.8	1.0	1.2
Total shrubs	29.8	1.1		3.2	8.6	12.0	18.9

Table 17-6.--Volume development of herb component (m^3/0.01 ha), fig. 17-6.

Species	Succession year						
	Pre	1	2*	3	4	5	6
Anemone piperi	-	-		-	-	0.1	-
Berberis repens	-	-		0.1	0.1	-	0.4
Calamagrostis rubescens	0.2	0.3		.8	3.4	2.4	2.2
Calamagrostis tweedyi	-	.1		.5	1.1	1.0	.9
Carex concinnoides	-	-		-	-	-	<.1
Carex rossii	-	-		.8	1.1	1.3	1.3
Epilobium paniculatum	-	-		.8	.1	-	-
Xerophyllum tenax	6.8	.7		.9	.7	1.6	1.2
Misc. herbs	1.0	.4		1.5	.7	.4	.4
Total herbs	8.0	1.5		5.5	7.2	6.8	6.3

*No data taken.

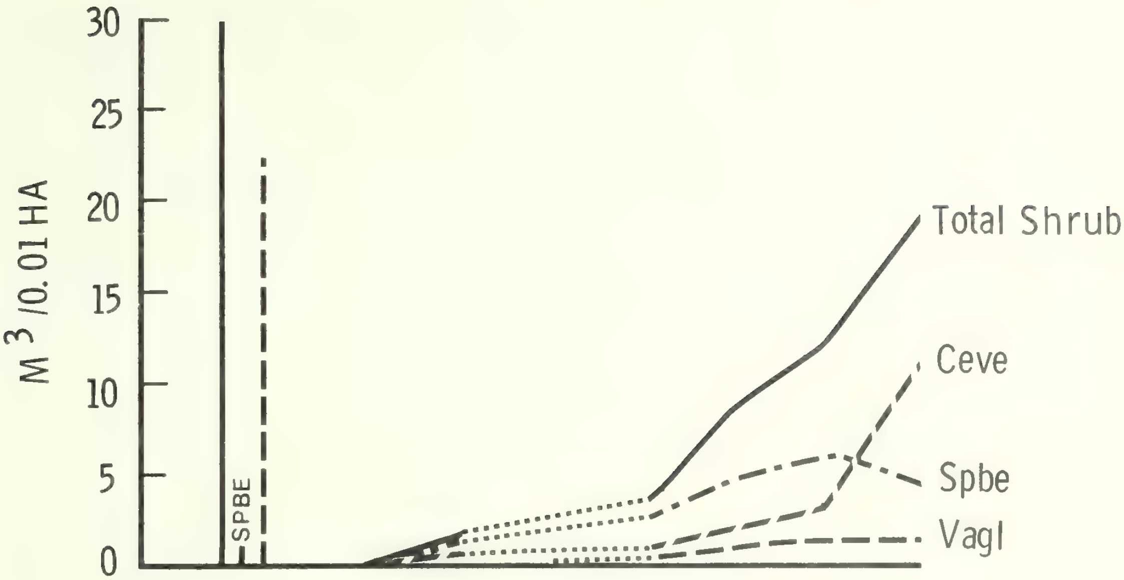


Figure 17-5. Shrub volume.

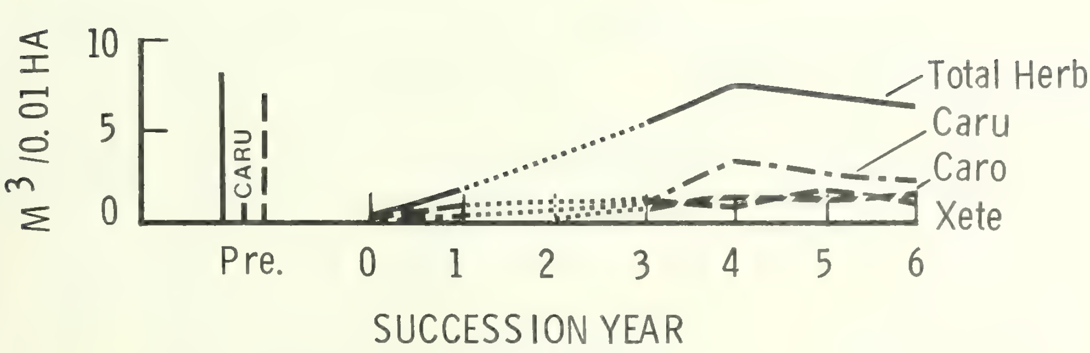


Figure 17-6. Herb volume.

MILLER CREEK: South-12 (1802-13 Area 22-3)

Site location and description: SE¼NE¼ Sec. 20, T32N R24W MPM.
Elevation: 4,550 ft; Exposure: South (Az. 180°); Slope: 15%
Habitat type: Abies lasiocarpa/Clintonia uniflora, Xerophyllum tenax Phase
Predisturbance forest stand: Laoc 54%, Psme 24%, Abla 12%, Pien 10%
(Stand basal area: 3,553 cm^2/0.01 ha)
Disturbance treatment: Unlogged; Wildfire: August 23, 1967
(Succession year 1:1968); Fire intensity: -- g water loss;
Duff moisture: Upper 24%, Lower 56%; Postfire duff depth: -- cm

Table 18-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 18-1.

Life-form component	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Tree	2	-	-	-	-	-	-	-	-	3
Shrub	73	-	2	8	8	11	22	24	52	54
Herb	54	15	38	55	40	43	41	35	35	35
Total veg.	129	15	40	63	48	54	63	59	87	91
Exposed ground surface:										
Bare ground	-	12	2	-	-	-	-	-	-	-
Rock	-	-	-	-	-	-	-	-	-	-
Litter	22	57	47	16	22	21	28	27	22	31
Moss	2	17	12	27	35	30	23	25	27	21

Table 18-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 18-2.

Life-form component	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Tree	0.7	-	-	-	-	-	-	-	-	4.0
Shrub	133.0	-	2.2	6.0	6.3	6.9	14.2	15.3	37.8	44.1
Herb	17.9	1.5	14.6	27.4	16.1	20.9	18.3	13.9	13.7	14.4
Total veg.	151.7	1.5	16.7	33.4	22.5	27.8	32.5	29.2	51.4	62.5

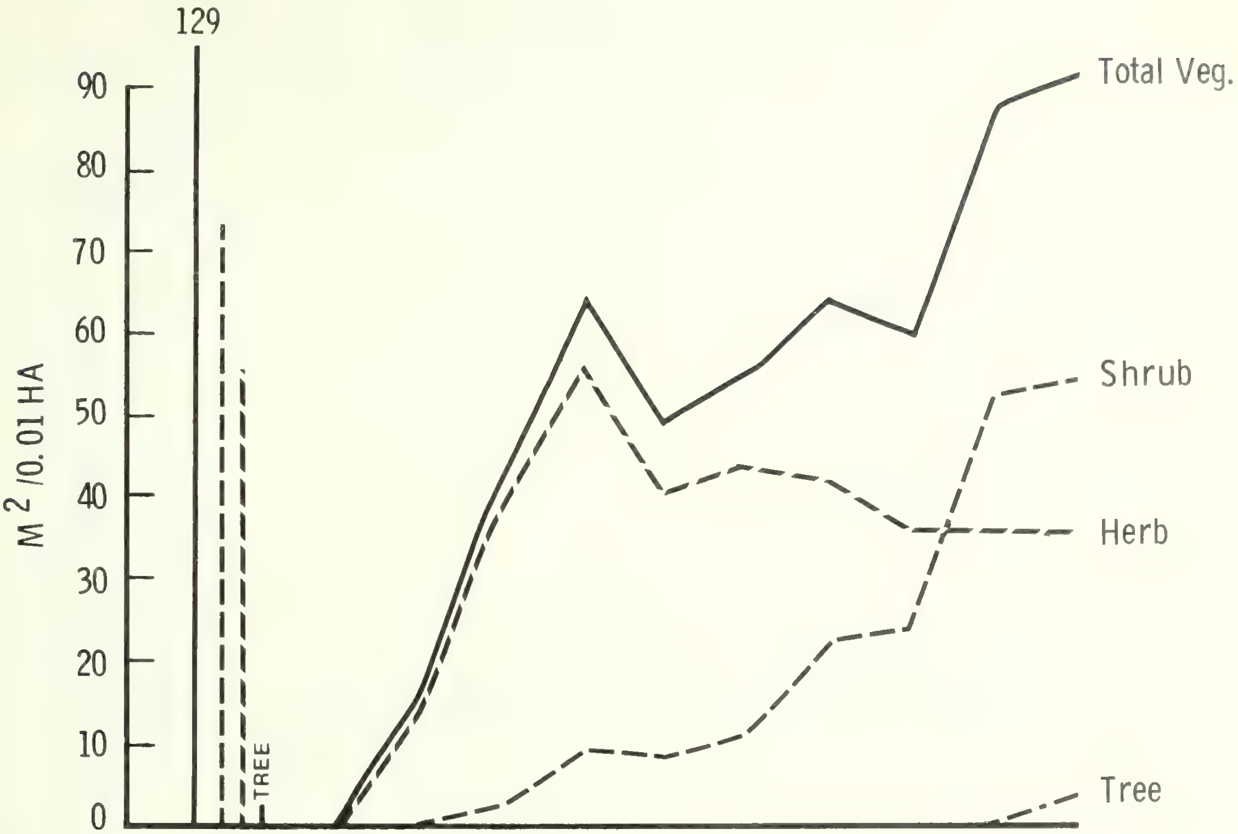


Figure 18-1. Vegetative cover.

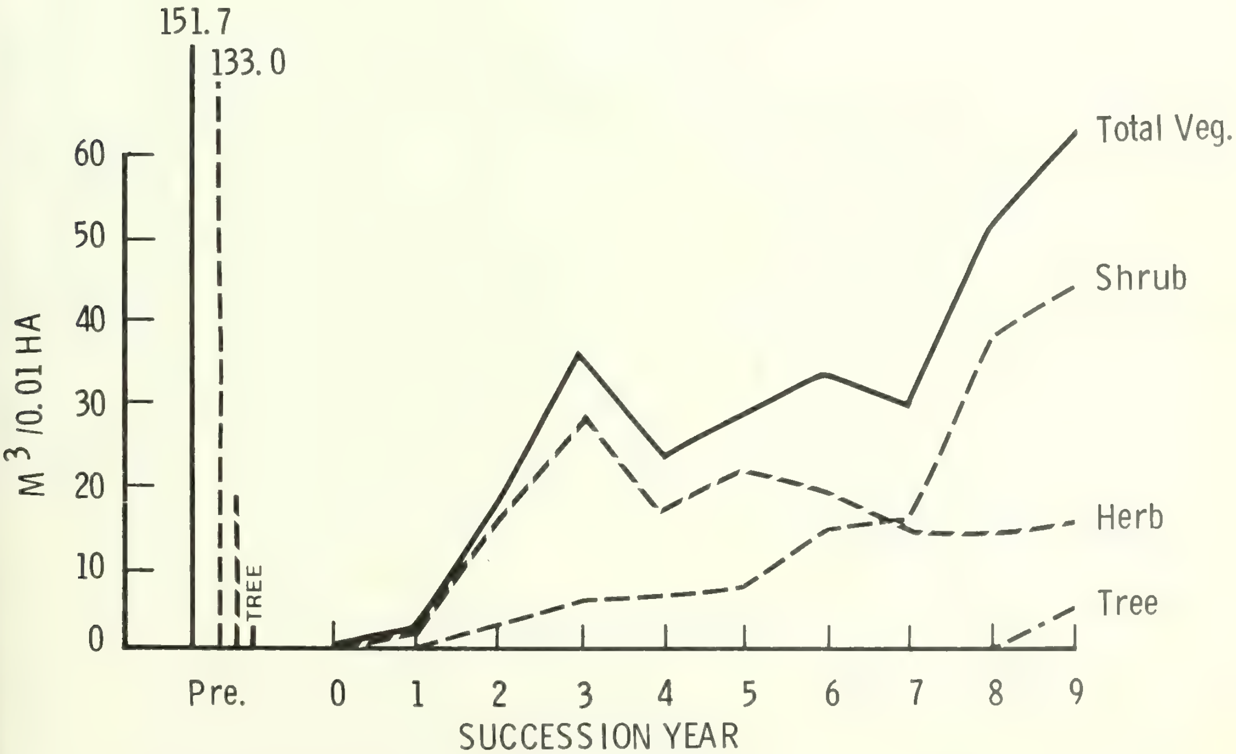


Figure 18-2. Vegetative volume.

Table 18-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 18-3.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Acer glabrum	16	-	1	2	3	3	2	3	3	3
Alnus sinuata	14	-	-	-	-	-	-	-	-	-
Amelanchier alnifolia	1	-	-	-	-	-	-	-	-	1
Ceanothus velutinus	-	-	-	1	-	-	7	9	25	26
Pachistima myrsinites	-	-	-	-	-	-	-	1	-	1
Rosa gymnocarpa	11	-	1	1	2	2	2	2	8	5
Salix scouleriana	-	-	-	-	-	-	3	3	5	10
Spiraea betulifolia	5	-	1	4	2	5	7	6	11	7
Symphoricarpos albus	1	-	-	-	-	-	-	-	-	-
Vaccinium globulare	26	-	-	-	2	1	1	1	1	2
Total shrubs	73	-	2	8	8	11	22	24	52	54

Table 18-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 18-4.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Anaphalis margaritaceae	-	-	-	-	-	-	4	3	5	3
Arnica latifolia	14	2	1	1	1	-	-	-	-	-
Berberis repens	2	-	-	1	1	1	2	2	2	1
Chimaphila umbellata	3	-	-	-	-	-	-	-	-	-
Cirsium vulgare	-	-	-	-	-	-	-	1	1	-
Epilobium angustifolium	-	12	34	46	36	37	28	23	21	22
Epilobium paniculatum	-	-	-	2	-	-	-	-	-	-
Gnaphalium viscosum	-	-	-	-	-	-	2	-	-	-
Pyrola secunda	1	-	-	-	-	-	-	-	-	-
Viola orbiculata	2	-	-	-	-	-	-	-	-	-
Xerophyllum tenax	29	-	-	1	1	2	1	2	2	2
Misc. herbs	2	1	3	4	2	4	3	4	5	6
Total herbs	54	15	38	55	40	43	41	35	35	35

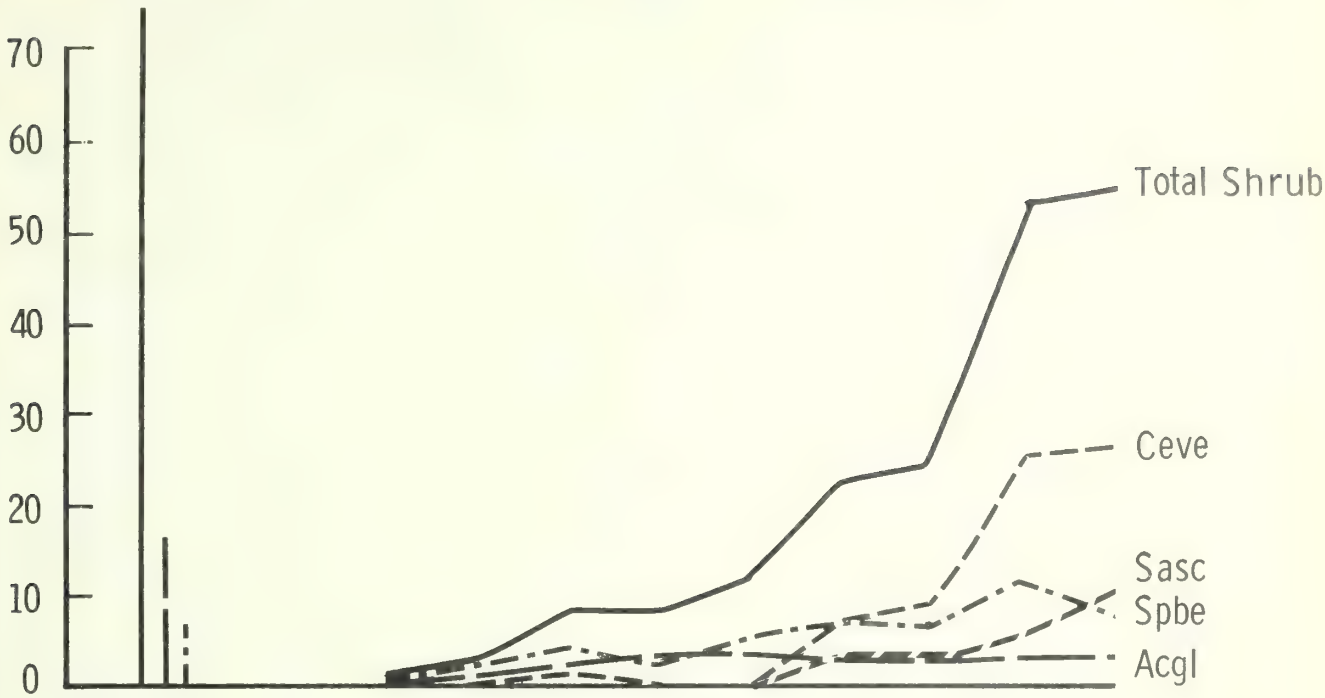


Figure 18-3. Shrub cover.

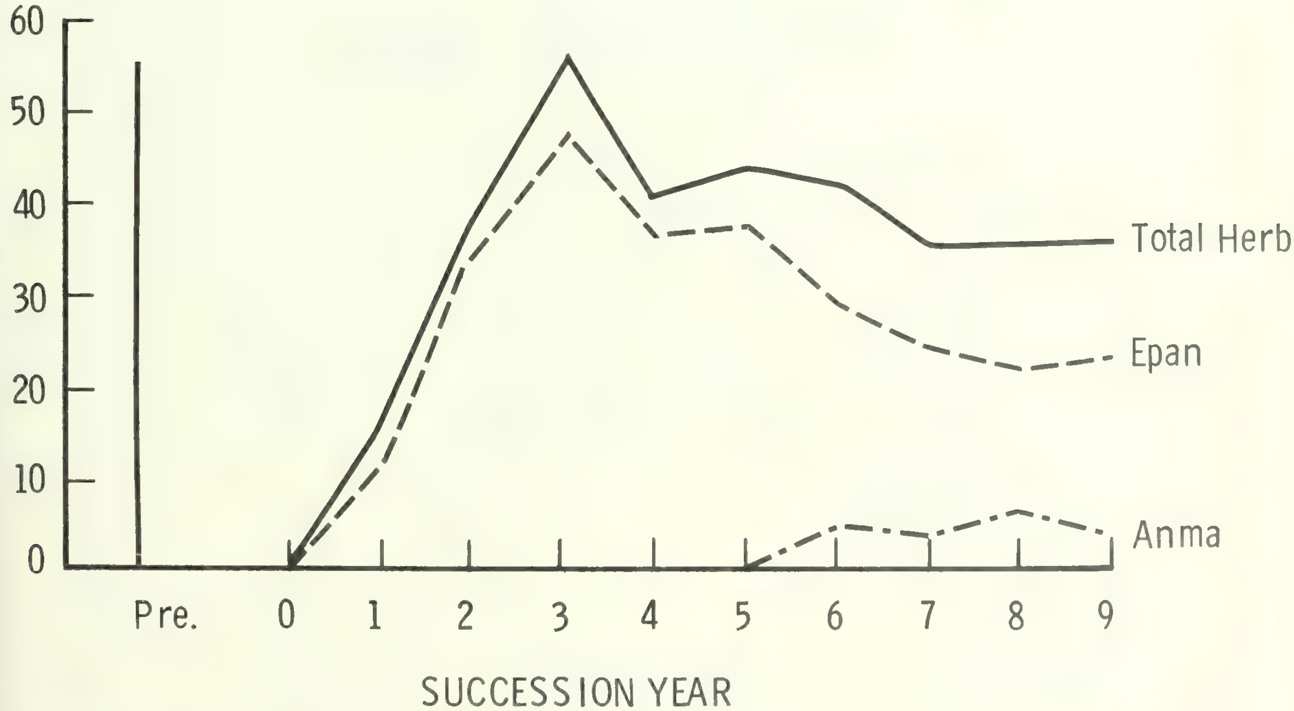


Figure 18-4. Herb cover.

MC: S-12 (A-22-3)

Table 18-5.--Volume development of shrub component (m^3/0.01 ha), fig. 18-5.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Acer glabrum	69.4	-	1.8	3.4	4.7	4.9	3.6	5.3	7.7	7.1
Alnus sinuata	40.5	-	-	-	-	-	-	-	-	-
Amelanchier alnifolia	.8	-	-	-	-	-	-	-	-	.8
Ceanothus velutinus	-	-	-	.1	-	-	3.4	3.5	13.3	17.2
Pachistima myrsinites	-	-	-	-	-	-	-	.2	-	.2
Rosa gymnocarpa	6.0	-	.1	.5	.6	.8	1.5	.4	5.2	3.2
Salix scouleriana	-	-	-	-	-	-	2.4	3.2	6.4	12.9
Spiraea betulifolia	1.9	-	.3	2.1	.8	1.1	3.2	2.5	5.1	2.4
Symphoricarpos albus	.2	-	-	-	-	-	-	-	-	-
Vaccinium globulare	14.2	-	-	-	.3	.1	.1	.2	.1	.3
Total shrubs	133.0	-	2.2	6.0	6.3	6.9	14.2	15.3	37.8	44.1

Table 18-6.--Volume development of herb component (m^3/0.01 ha), fig. 18-6.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Anaphalis margaritaceae	-	-	-	-	-	-	1.1	1.1	1.5	1.1
Arnica latifolia	2.5	0.1	0.2	0.1	0.1	-	-	-	-	-
Berberis repens	5.4	-	-	<.1	.1	0.1	.3	.2	.2	<.1
Chimaphila umbellata	.4	-	-	-	-	-	-	-	-	-
Cirsium vulgare	-	-	-	-	-	-	-	.1	.2	-
Epilobium angustifolium	-	1.4	13.5	26.1	15.6	20.0	15.4	11.4	10.5	11.4
Epilobium paniculatum	-	-	-	.5	-	-	-	-	-	-
Gnaphalium viscosum	-	-	-	-	-	-	.5	-	-	-
Pyrola secunda	.1	-	-	-	-	-	-	-	-	-
Viola orbiculata	.1	-	-	-	-	-	-	-	-	-
Xerophyllum tenax	9.0	-	-	.2	.2	.4	.2	.5	.4	.7
Misc. herbs	.4	<.1	.8	.4	.2	.5	.7	.6	.8	1.2
Total herbs	17.9	1.5	14.6	27.4	16.1	20.9	18.3	13.9	13.7	14.4

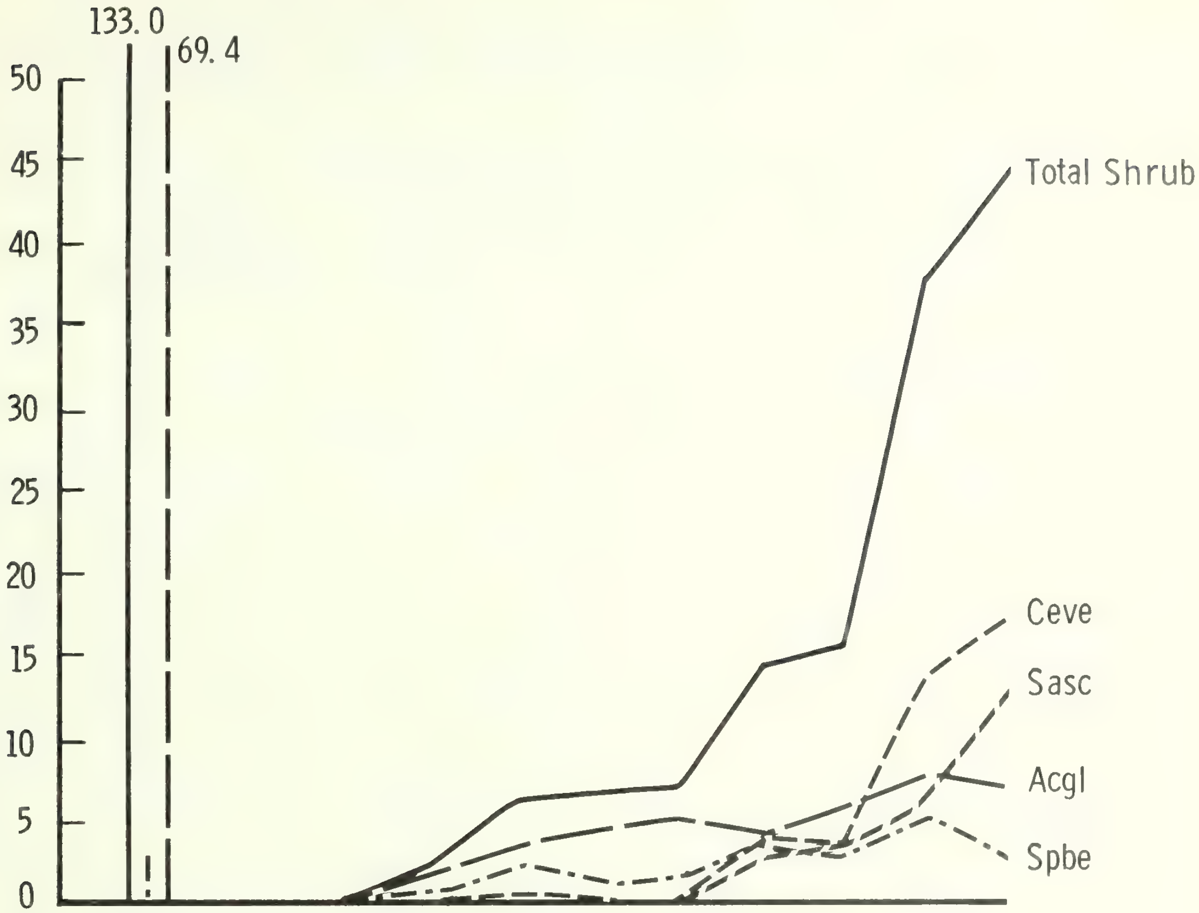


Figure 18-5. Shrub volume.

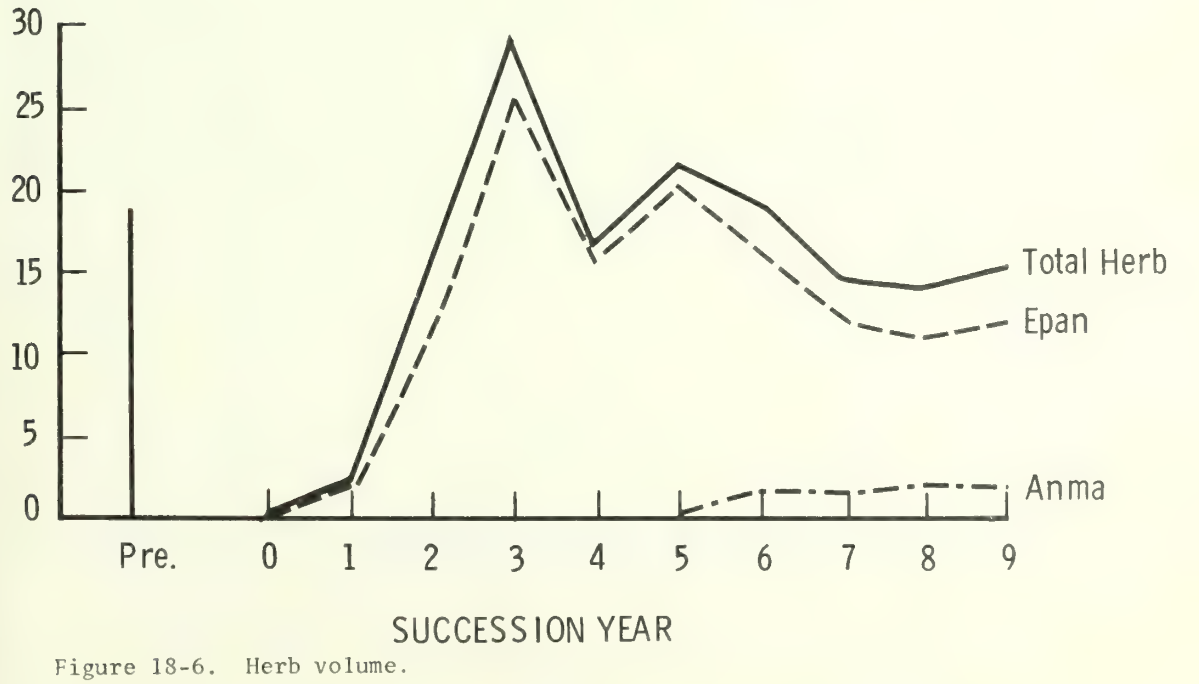


Figure 18-6. Herb volume.

MILLER CREEK: South-13 (1802-13 Area 22-1)

Site location and description: SE¼NE¼ Sec. 20, T32N R24W MPM.
Elevation: 4,600 ft; Exposure: South (Az. 200°); Slope: 30%
Habitat type: Abies lasiocarpa/Clintonia uniflora, Xerophyllum tenax Phase
Predisturbance forest stand: Pien 30%, Laoc 22%, Abla 21%, Psme 20%, Pico 7% (Stand basal area: 2,491 cm^2/0.01 ha)
Disturbance treatment: Unlogged; Wildfire: August 23, 1967 (Succession year 1:1968); Fire intensity: -- g water loss; Duff moisture: Upper 24%, lower 56%; Postfire duff depth: -- cm

Table 19-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 19-1.

Life-form component	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Tree	-	-	-	-	2	2	1	2	1	19
Shrub	80	3	7	10	18	17	27	34	66	55
Herb	37	2	15	34	37	27	24	25	22	27
Total veg.	117	5	22	44	56	47	52	61	89	100
Exposed ground surface:										
Bare ground	-	9	5	4	1	2	-	1	1	-
Rock	-	2	2	2	2	-	2	1	3	2
Litter	23	65	36	18	16	17	23	22	17	23
Moss	2	20	39	33	32	40	34	29	32	26

Table 19-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 19-2.

Life-form component	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Tree	-	-	-	-	0.4	0.9	0.3	0.5	0.3	28.3
Shrub	75.0	1.4	4.2	5.6	13.5	14.5	18.4	23.4	44.6	40.4
Herb	7.1	.2	5.6	12.9	12.6	11.2	9.5	8.2	7.6	11.2
Total veg.	82.1	1.6	9.9	18.5	26.6	26.6	28.3	32.1	52.5	79.9

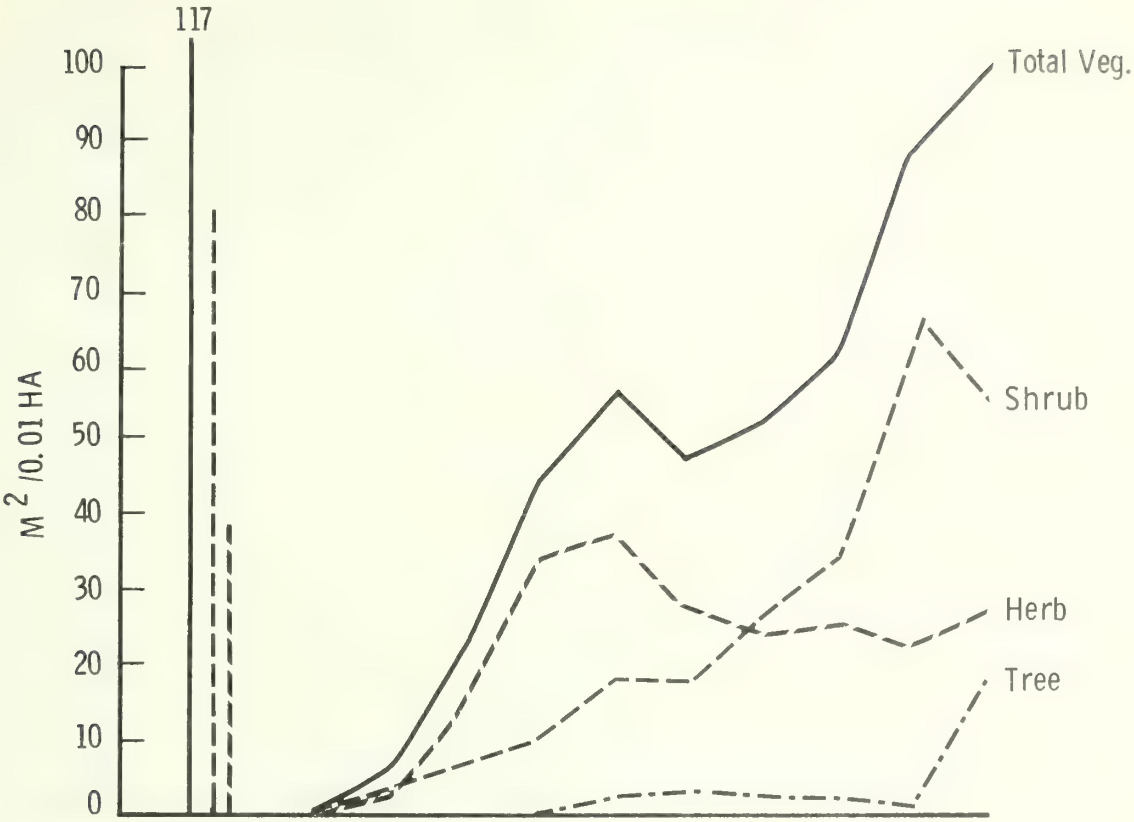


Figure 19-1. Vegetative cover.

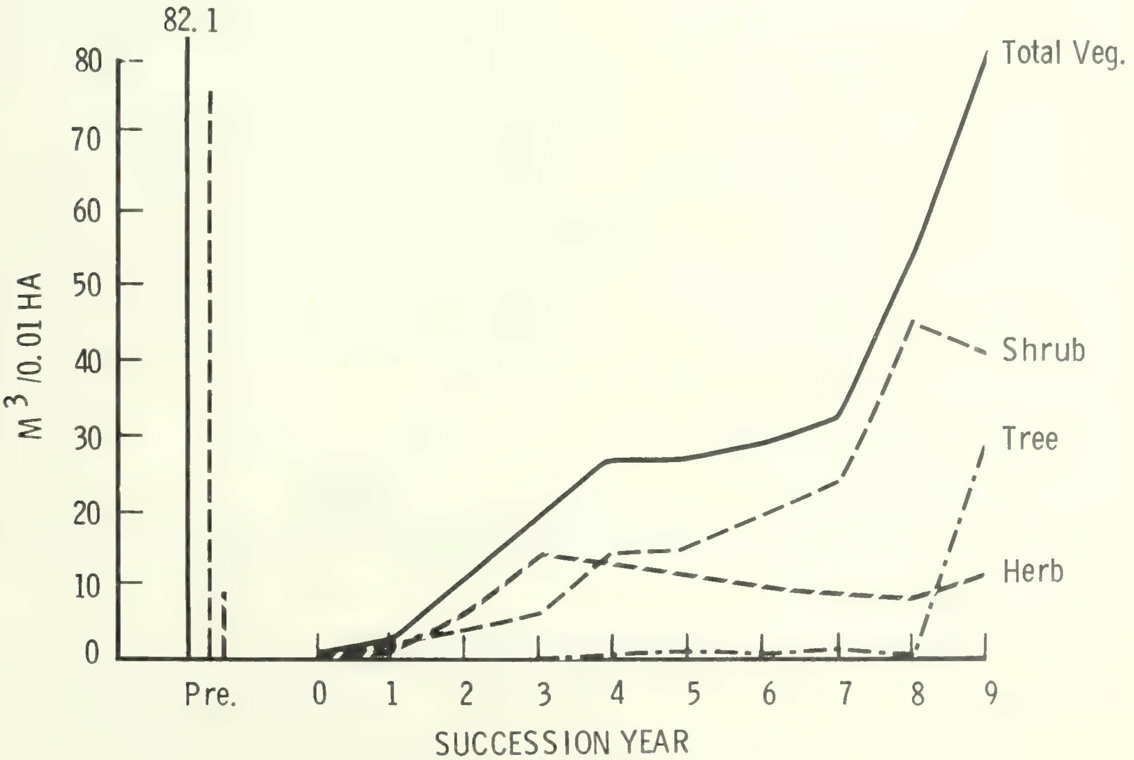


Figure 19-2. Vegetative volume.

Table 19-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 19-3.

Species	Succession year: Pre	1	2	3	4	5	6	7	8	9
Acer glabrum	11	1	2	1	4	4	4	4	6	4
Ceanothus velutinus	-	-	-	2	-	-	5	18	38	29
Rosa gymnocarpa	1	-	1	<1	1	1	1	-	1	<1
Salix scouleriana	-	-	-	-	-	1	1	<1	3	<1
Spiraea betulifolia	9	2	4	7	11	11	15	11	14	16
Vaccinium globulare	54	-	-	1	1	1	1	1	4	6
Vaccinium myrtillus	5	-	-	-	-	-	-	-	-	-
Total shrubs	80	3	7	10	18	17	27	34	66	55

Table 19-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 19-4.

Species	Succession year: Pre	1	2	3	4	5	6	7	8	9
Berberis repens	1	-	-	-	-	-	-	-	-	-
Bromus vulgaris	1	-	-	-	-	-	-	-	-	-
Calamagrostis rubescens	-	-	-	1	1	1	1	2	3	6
Carex concinnoides	2	-	-	-	-	1	1	1	-	1
Chimaphila umbellata	4	-	-	-	-	-	-	-	-	-
Epilobium angustifolium	-	-	10	22	26	16	9	7	7	10
Epilobium paniculatum	-	-	-	3	1	-	-	-	-	-
Hieracium albiflorum	1	-	-	-	-	-	-	-	-	-
Linnaea borealis	2	-	-	-	-	-	-	-	-	-
Xerophyllum tenax	23	2	3	2	4	5	8	8	6	9
Misc. herbs	3	-	2	5	5	5	6	8	6	1
Total herbs	37	2	15	34	37	27	24	25	22	27

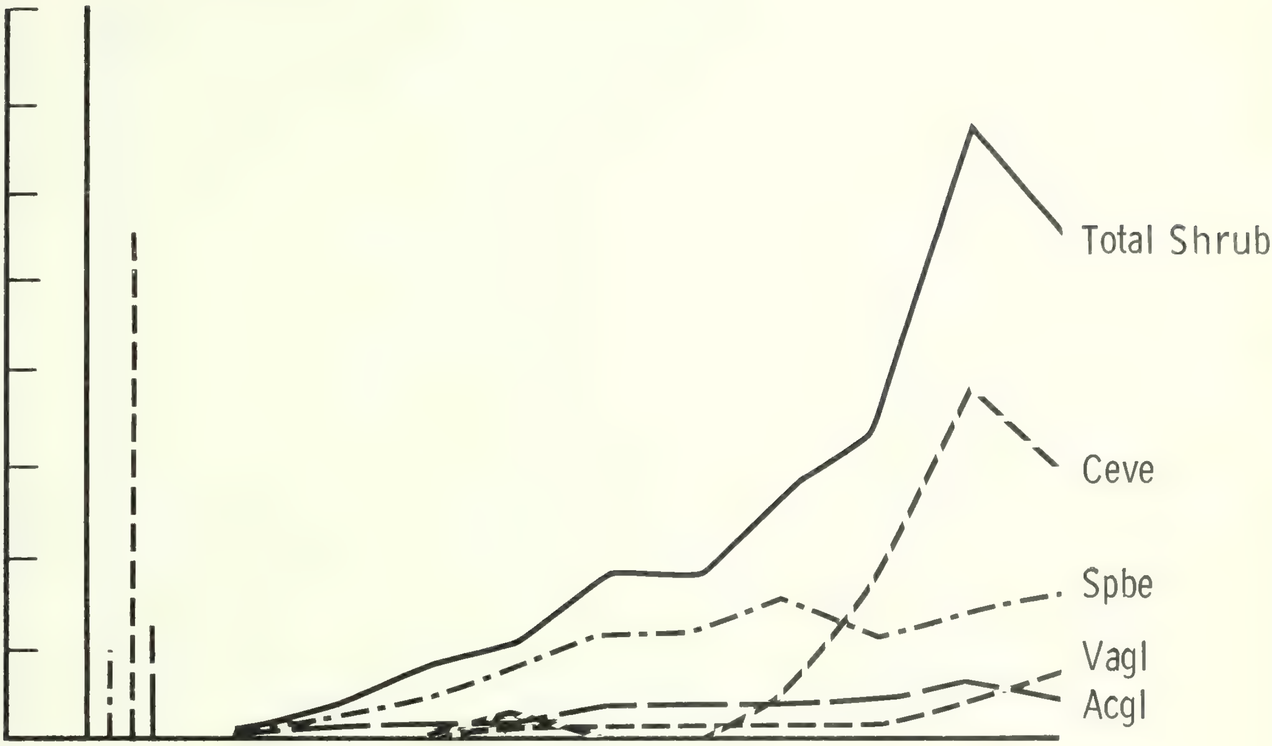


Figure 19-3. Shrub cover.

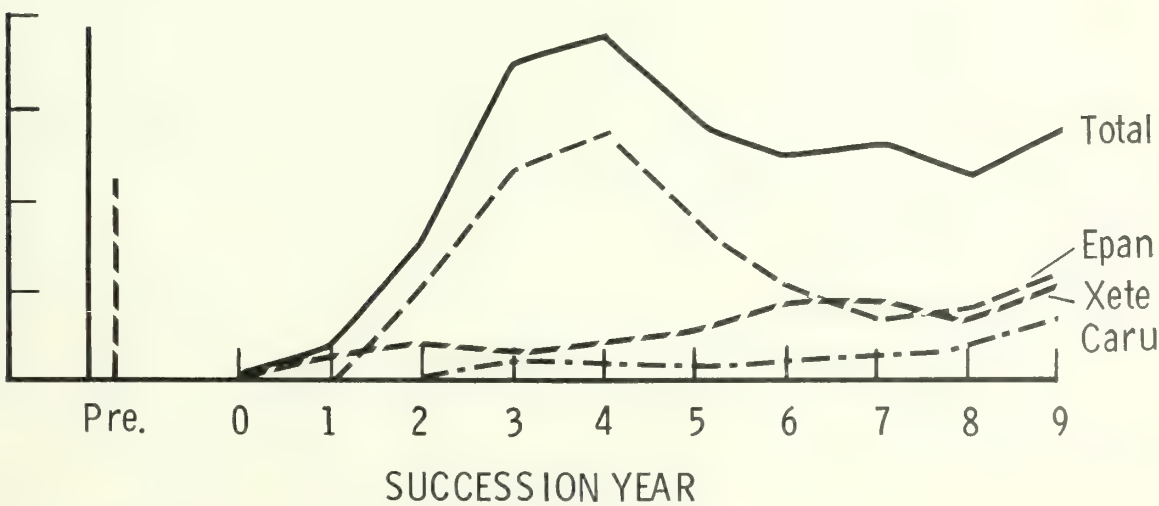


Figure 19-4. Herb cover.

Table 19-5.--Volume development of shrub component (m^3/0.01 ha), fig. 19-5.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Acer glabrum	45.0	0.9	2.4	2.5	8.5	9.1	9.6	10.6	12.3	10.5
Ceanothus velutinus	-	-	-	.2	-	-	1.9	8.6	23.6	23.4
Rosa gymnocarpa	.6	-	.4	.2	1.0	.6	.4	-	.3	.1
Salix scouleriana	-	-	-	-	-	.5	.5	.2	2.7	.3
Spiraea betulifolia	2.3	.5	1.4	2.6	3.9	4.1	5.9	3.9	5.2	5.2
Vaccinium globulare	26.3	-	-	.1	.1	.1	.1	.1	.6	1.0
Vaccinium myrtillus	.8	-	-	-	-	-	-	-	-	-
Total shrubs	75.0	1.4	4.2	5.6	13.5	14.5	18.4	23.4	44.6	40.4

Table 19-6.--Volume development of herb component (m^3/0.01 ha), fig. 19-6.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Berberis repens	0.2	-	-	-	-	-	-	-	-	-
Bromus vulgaris	.2	-	-	-	-	-	-	-	-	-
Calamagrostis rubescens	-	-	-	0.3	<0.1	0.2	0.2	0.5	1.0	2.2
Carex concinnoides	.8	-	-	-	-	<.1	.1	.1	-	.2
Chimaphila umbellata	.4	-	-	-	-	-	-	-	-	-
Epilobium angustifolium	-	-	4.4	9.9	10.9	8.8	5.1	3.4	3.7	5.8
Epilobium paniculatum	-	-	-	.7	<.1	-	-	-	-	-
Hieracium albiflorum	<.1	-	-	-	-	-	-	-	-	-
Linnaea borealis	.1	-	-	-	-	-	-	-	-	-
Xerophyllum tenax	5.8	0.2	.8	.8	.9	1.1	2.4	1.8	1.6	2.8
Misc. herbs	.3	-	.4	1.3	.8	1.0	1.6	2.4	1.3	.2
Total herbs	7.1	.2	5.6	12.9	12.6	11.2	9.5	8.2	7.6	11.2

Figure 19-5. Shrub volume.

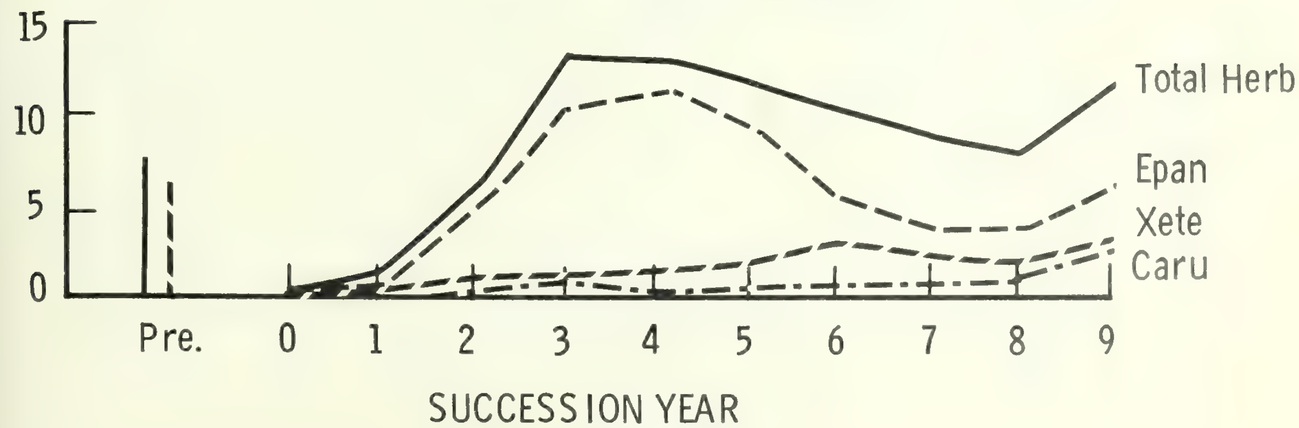


Figure 19-6. Herb volume.

MILLER CREEK: West-6 (1802-13 Area 23)

Site location and description: SW¼NE¼ Sec. 21, T32N R24W MPM.
Elevation: 4,300 ft; Exposure: West (Az. 255°); Slope: 15%
Habitat type: Abies lasiocarpa/Clintonia uniflora, Xerophyllum tenax Phase
Predisturbance forest stand: Psme 35%, Abla 33%, Laoc 16%, Pico 15%, Pien 1% (Stand basal area: 3,788 cm^2/0.01 ha)
Disturbance treatment: Unlogged; Wildfire: August 23, 1967 (Succession year 1:1968); Fire intensity: -- g water loss; Duff moisture: Upper 24%, Lower 56%; Postfire duff depth: -- cm

Table 20-1.--Successional development of vegetative cover (m^2/0.01 ha or %), fig. 20-1.

Life-form component	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Tree	-	-	-	-	-	-	1	-	2	13
Shrub	88	1	2	3	4	10	10	16	25	27
Herb	47	14	42	51	43	48	43	34	46	36
Total veg.	135	15	44	54	47	58	55	50	73	75
Exposed ground surface:										
Bare ground	-	1	-	-	-	-	-	-	1	-
Rock	-	-	-	-	-	-	-	-	-	-
Litter	16	79	37	27	28	27	32	31	14	22
Moss	3	5	20	20	24	17	16	21	22	20

Table 20-2.--Successional development of vegetative volume (m^3/0.01 ha), fig. 20-2.

Life-form component	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Tree	-	-	-	-	-	-	0.2	-	0.5	8.6
Shrub	75.2	0.2	0.4	1.1	1.4	3.4	3.9	5.2	12.0	11.9
Herb	10.5	1.2	13.7	20.2	15.3	18.0	14.3	9.6	14.0	10.9
Total veg.	85.7	1.3	14.2	21.2	16.7	21.4	18.5	14.8	26.5	31.5

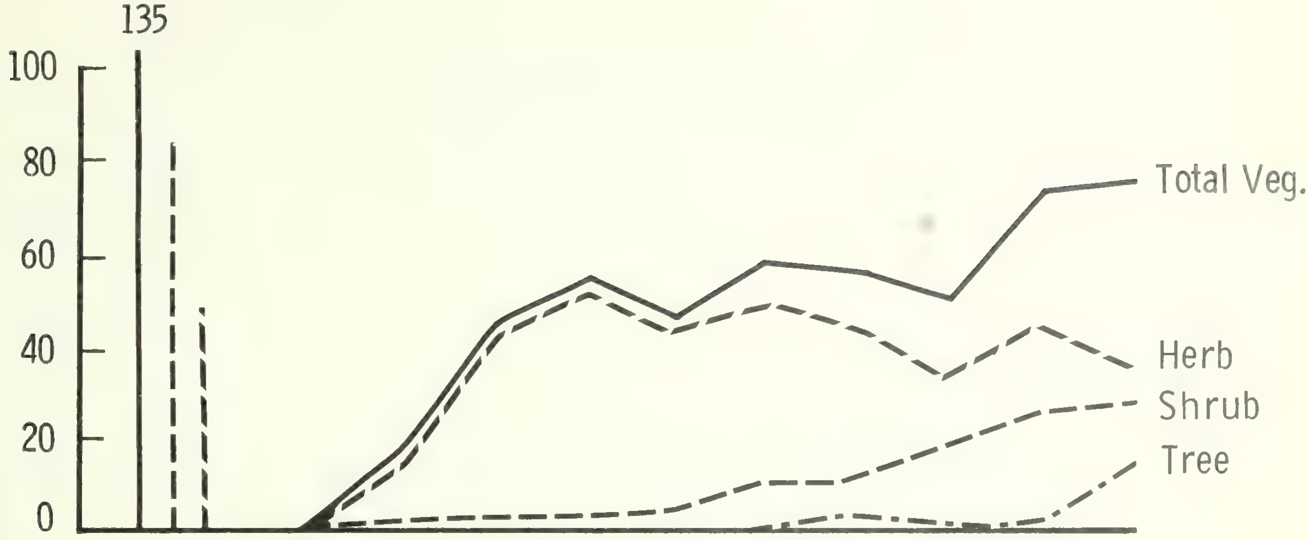


Figure 20-1. Vegetative cover.

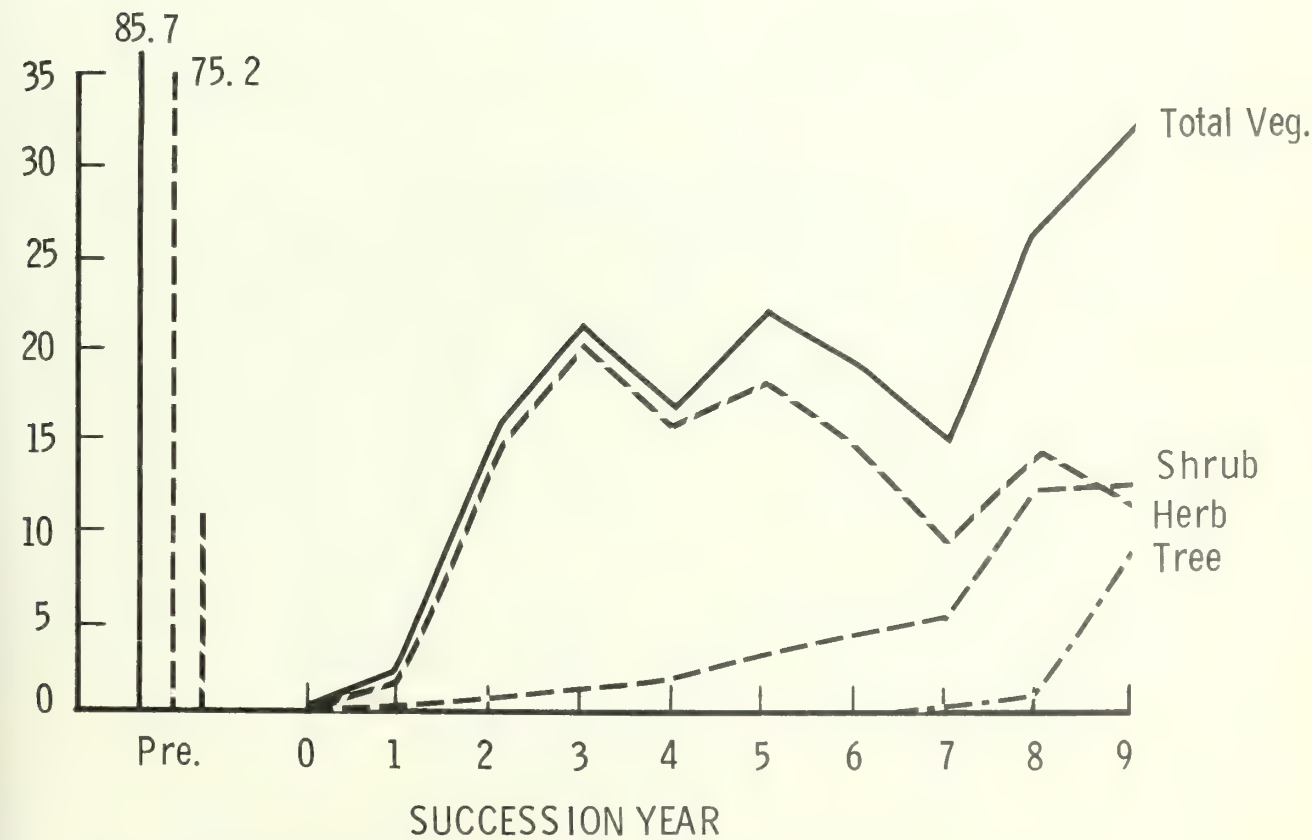


Figure 20-2. Vegetative volume.

MC: W-6 (A-23)

Table 20-3.--Cover development of shrub component (m^2/0.01 ha or %), fig. 20-3.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Acer glabrum	8	<1	-	-	-	-	-	-	1	<1
Lonicera utahensis	4	-	-	-	1	2	-	2	-	-
Pachistima myrsinites	2	-	-	-	-	-	-	-	-	-
Rosa gymnocarpa	2	-	<1	1	-	2	1	2	4	2
Salix scouleriana	-	-	2	-	-	2	2	3	9	10
Shepherdia canadensis	16	-	-	-	-	-	-	-	-	-
Spiraea betulifolia	9	1	-	2	3	5	5	8	9	11
Taxus brevifolia	8	-	-	-	-	-	-	-	-	-
Vaccinium globulare	40	-	-	-	-	-	2	1	2	3
Total shrubs	88	1	2	3	4	10	10	16	25	27

Table 20-4.--Cover development of herb component (m^2/0.01 ha or %), fig. 20-4.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Arnica latifolia	2	1	-	2	2	1	2	-	1	-
Aster conspicuus	-	-	-	-	-	-	-	-	1	-
Carex concinnoides	-	-	-	-	-	-	-	-	1	-
Chimaphila umbellata	1	-	-	-	-	-	-	-	-	-
Epilobium angustifolium	-	9	37	42	31	37	26	20	19	18
Linnaea borealis	5	-	-	-	-	-	1	-	2	1
Pyrola uniflora	1	-	-	-	-	-	-	-	-	-
Xerophyllum tenax	32	3	2	4	8	6	7	8	13	10
Misc. herbs	7	1	2	3	2	5	8	7	9	7
Total herbs	47	14	42	51	43	48	43	34	46	36

Figure 20-3. Shrub cover.

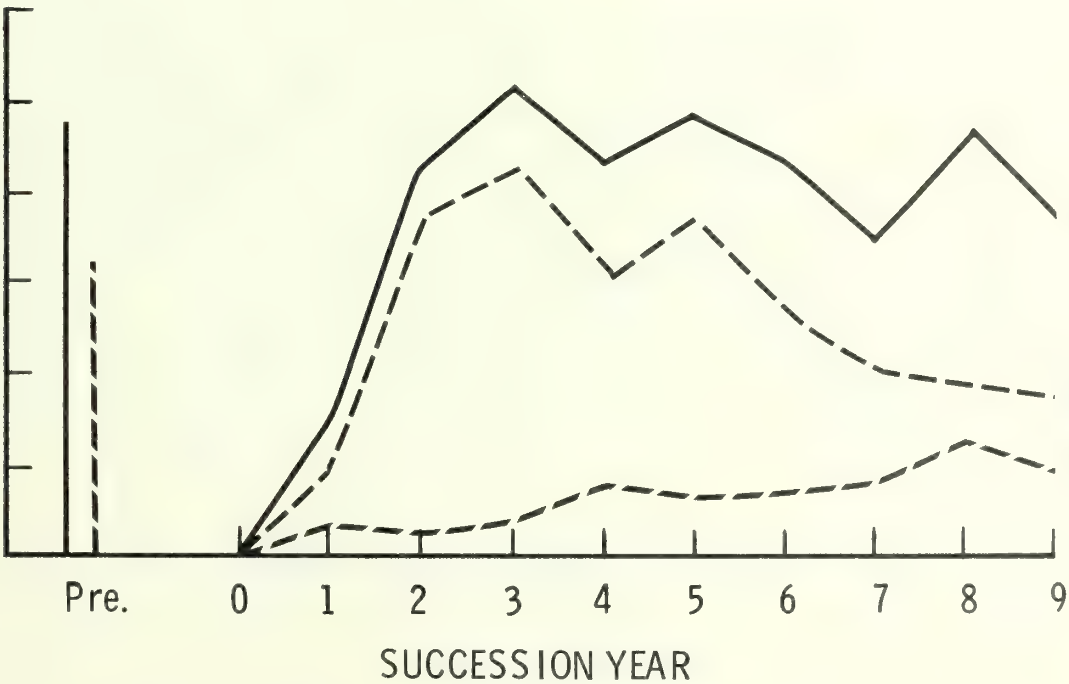


Figure 20-4. Herb cover.

Table 20-5.--Volume development of shrub component (m^3/0.01 ha), fig. 20-5.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Acer glabrum	16.9	0.1	-	-	-	-	-	-	0.5	0.2
Lonicera utahensis	1.7	-	-	-	0.4	0.7	-	0.4	-	-
Pachistima myrsinites	.2	-	-	-	-	-	-	-	-	-
Rosa gymnocarpa	1.3	-	0.1	0.3	-	.8	0.8	.6	.9	.8
Salix scouleriana	-	-	.3	-	-	.6	1.4	1.8	6.6	7.4
Shepherdia canadensis	15.2	-	-	-	-	-	-	-	-	-
Spiraea betulifolia	3.0	.1	-	.8	1.0	1.4	1.5	2.2	3.4	3.1
Taxus brevifolia	16.0	-	-	-	-	-	-	-	-	-
Vaccinium globulare	20.9	-	-	-	-	-	.2	.2	.6	.4
Total shrubs	75.2	.2	.4	1.1	1.4	3.4	3.9	5.2	12.0	11.9

Table 20-6.--Volume development of herb component (m^3/0.01 ha), fig. 20-6.

Species	Succession year									
	Pre	1	2	3	4	5	6	7	8	9
Arnica latifolia	0.3	<0.1	-	0.2	0.1	<0.1	0.1	-	0.1	-
Aster conspicuus	-	-	-	-	-	-	-	-	.4	-
Carex concinnoides	-	-	-	-	-	-	-	-	.1	-
Chimaphila umbellata	.1	-	-	-	-	-	-	-	-	-
Epilobium angustifolium	-	.7	13.1	18.3	13.1	16.0	11.1	7.2	9.0	8.0
Linnaea borealis	.2	-	-	-	-	-	<.1	-	.2	<.1
Pyrola uniflora	<.1	-	-	-	-	-	-	-	-	-
Xerophyllum tenax	9.0	.4	.3	1.0	1.7	1.2	1.5	1.4	2.5	2.2
Misc. herbs	.9	<.1	.3	.6	.4	.8	1.5	1.0	1.8	.7
Total herbs	10.5	1.2	13.7	20.2	15.3	18.0	14.3	9.6	14.0	10.9

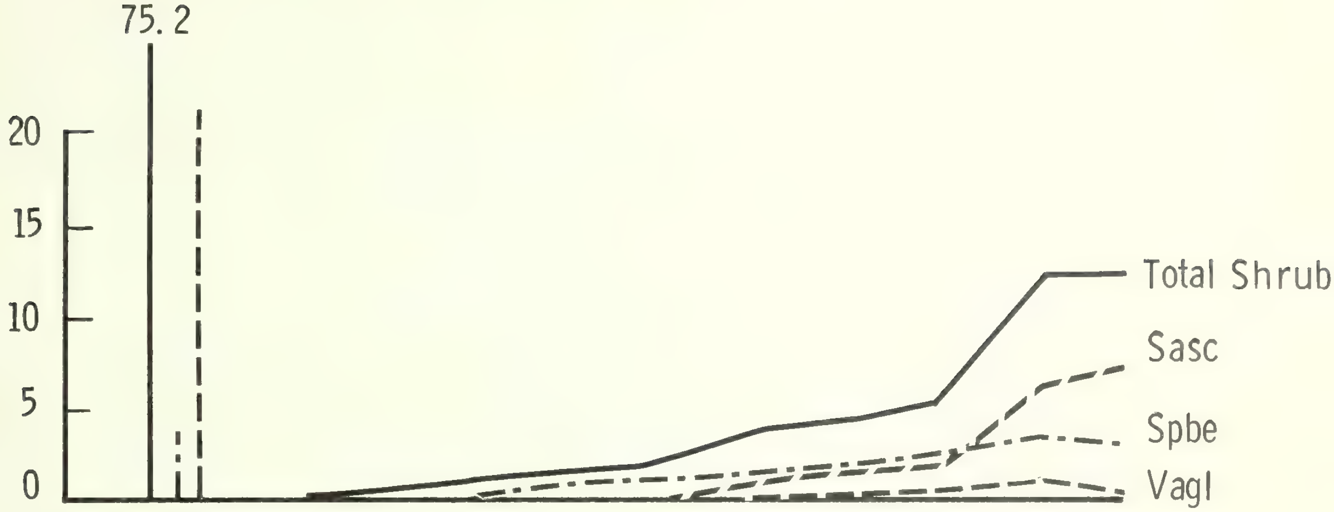


Figure 20-5. Shrub volume.

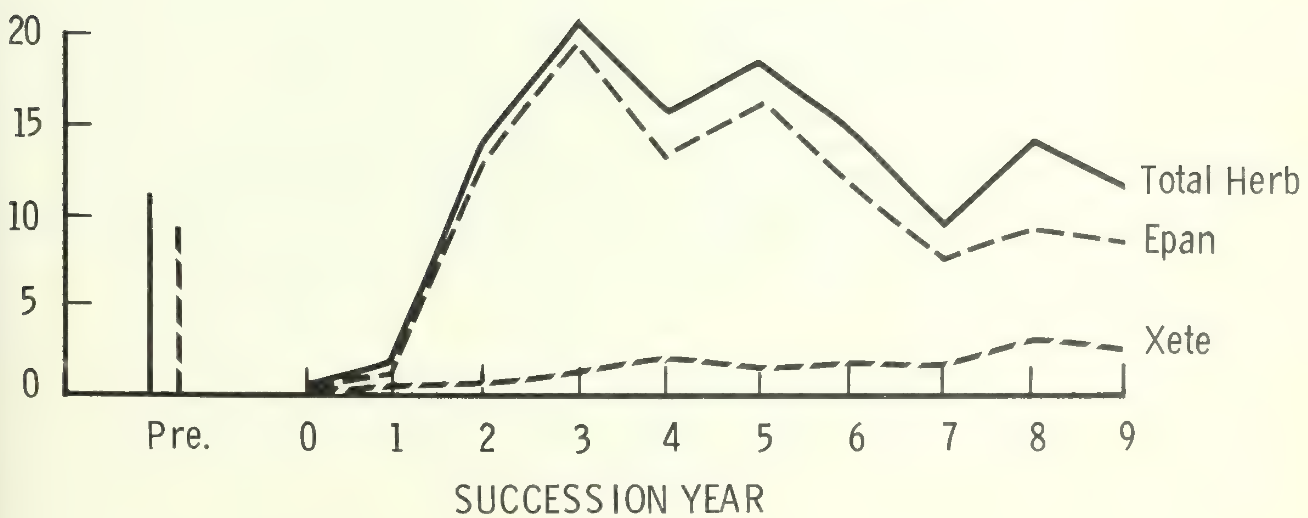


Figure 20-6. Herb volume.

Stickney, Peter F.
1980. Data base for post-fire succession, first 6 to 9 years, in Montana larch-fir forests. USDA For. Serv. Gen. Tech. Rep. INT-62, 133 p. Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.

Provides base line data on cover and volume development of plant species and life forms in the initial 6 to 9 years following disturbance by clearcut logging and fire or wild-fire in Montana's western larch-Douglas-fir forest type. Successional data is presented in basic form (m^2 or m^3/0.01 ha) for analytical use by others in modeling forest development and other forest management applications.

KEYWORDS: forest succession, fire succession, secondary plant succession, successional data base, initial successional stages, western larch type, Douglas-fir type.

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The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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Provo, Utah (in cooperation with Brigham Young University)

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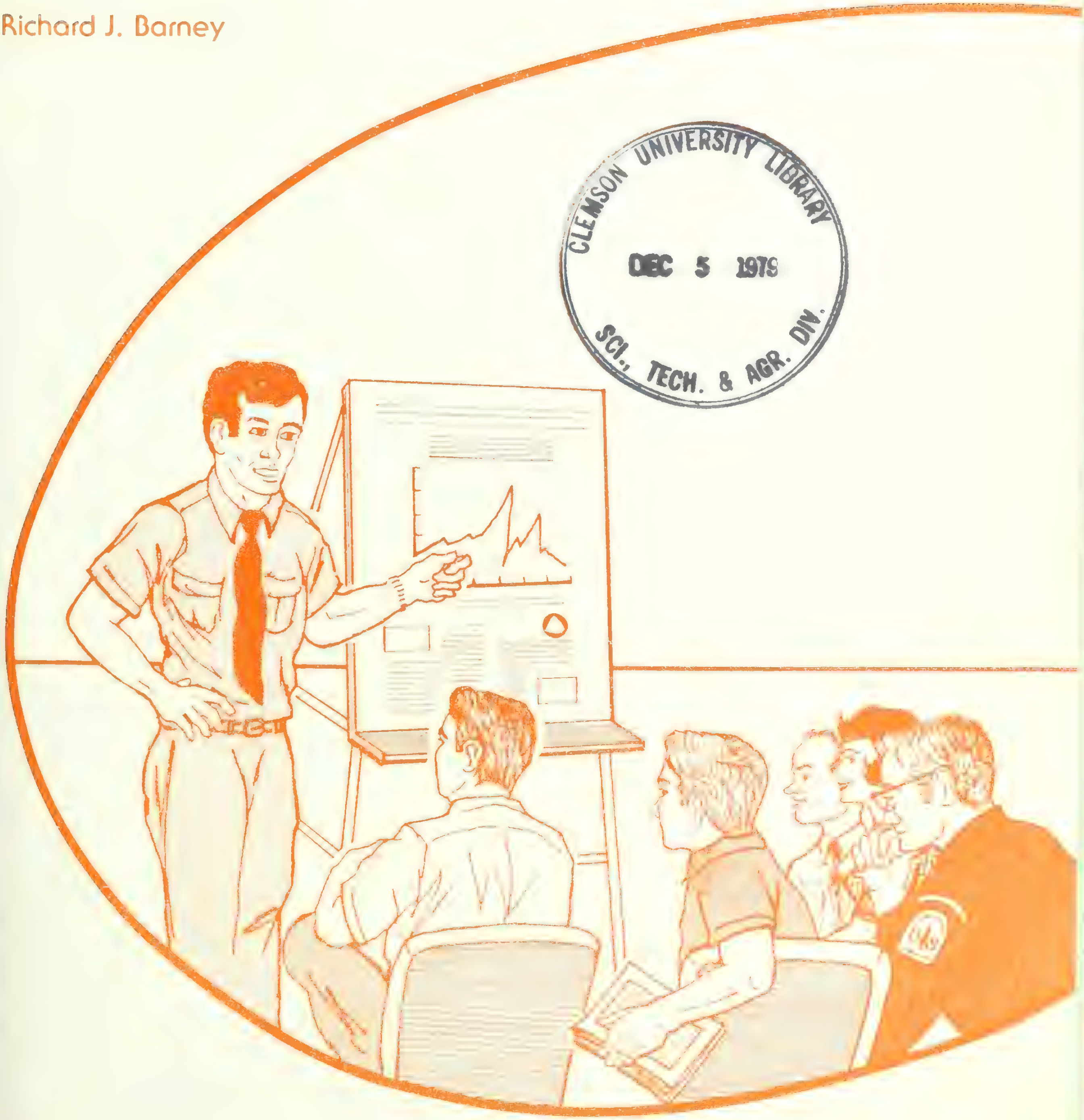
WILDLAND FIRE RESEARCH NEEDS IN THE WEST:

FOREST SERVICE MANAGERS' VIEWS

Richard J. Barney



USDA Forest Service General Technical Report INT-63
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE

USDA Forest Service
General technical Report INT-63
September 1979

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Forest Service
U. S. Department of Agriculture
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RESEARCH SUMMARY

Three questions regarding fire research needs were given to 355 respondents at 68 western Forest Service locations. Responses were categorized and summarized.

The inital question was "What kind of systems and support should research provide to help you integrate fire into land use planning?" Answers were processed into 12 categories, which were then ranked on the basis of frequency of response. Rankings of the top five or six categories were almost identical. Managers responding to this question mainly want better communication with researchers and improved transfer of research technology to management activities. State-of-the-art and "how-to" publications were thought important means of conveying information.

The second-ranked category included the need for economic evaluations, benefit-cost ratios, tradeoff and alternative evaluations, and value systems. Essentially all the responses in this category were economically oriented, indicating the current need to justify management decisions. Interest was strong in prescribed burning, fire use, and smoke management; and ranked third out of the 12 categories. Management practices ranked fourth. Here interviewees stated that they wanted better over-all guidance, more direction, and more detail in their land management planning activities. Fire effects and the effects of fire control ranked fifth. Respondents indicated a need to understand more thoroughly the effects of fire including the primary, secondary, direct, and indirect impact. The sixth ranked category dealt with the fire management activities of fire control and included fire behavior, fire danger rating needs. Managers wanted clarification of the relationship between land use planning and fire management planning and further indicated that tools and processes were needed to tie fire management planning more closely to the total resource planning process. Information, storage, and retrieval systems made up the seventh ranked category. Respondents felt that an information system should be affordable and usable by the local practitioners, rather than requiring special personnel.

Category eight included fuel prediction, inventory procedures, or in general, fuel management. Basically, managers wanted to know how to manage fuels--specifically what must be considered, including nutrient cycling.

The ninth-ranked category dealt with the need to obtain feedback and evaluation in the review processes between research and management. This would update information for managers and outline management's needs.

The tenth-ranked category was closely allied to the information and retrieval systems category previously mentioned, and was concerned with computer hardware and software, and analysis and display procedures. Field personnel expressed a need for use of computers to assist them in their management activities in all areas.

Category eleven covered hazard evaluation and fire probabilities. One specific question was: Can we predict the increase in hazard resulting from management activities? Is the magnitude of the increase predictable, can guidelines be developed to assist in making these predictions?

The twelfth and last category dealth with fire ecology. Managers need a means for defining succession following fires of various intensities based on prefire vegetative classification systems.

The second question asked in the survey was: What kind of accuracy and resolution do you need now, what would you like eventually? Most respondents felt that any improvements over today's capabilities would be helpful. They indicated that 99 percent accuracy was not needed and perhaps not attained.

The third and last question was: "When the RD&A is developing processes and procedures, would you have time to respond and to provide input?" do you want to be involved? Response to all questions was, "Yes".

Results obtained in this study provided additional guidance for defining and setting priorities for wildfire-related research in the western regions of the Forest Service.

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INTRODUCTION

In August 1973, the USDA Forest Service established the *Fire in Multiple-Use-Management Research, Development, and Application Program* (RD&A).[1] Development of this program was one response to the reality that the Forest Service, like other agencies in the public land management, is moving toward a policy in which fire, under careful controls, will be used to support forest and rangeland ecosystems management programs.

A study initiated in 1975 was directed toward one program goal, to develop methods for incorporating fire management into land-management plans.[2] This study was based on a sample taken from throughout the western regions of the National Forest System. Contacts were made in each regional office and selected forest headquarters and ranger districts in each of these regions. At each organizational level, personnel in fire management, land-use planning, timber, range, watershed, wildlife, recreation management, and State and Private Forestry were contacted.

Upon completion, results were analyzed then summarized and categorized. Results provided guidance for the RD&A program and development and modifications of planning procedures that include fire management considerations. An important result has been to more precisely define problems and to provide the RD&A program with specific direction.

This report discusses fire-related research needs in the western regions of the Forest Service. These needs were expressed by personnel at all management levels. Responses were one part of a more general study designed to establish information requirements for integrating fire into land management planning.

Researchers and managers alike need aids and good information in making management decisions that affect land use-fire management planning; no procedures or systems can be designed to adequately satisfy user needs without a thorough understanding of these needs.[3]

NEEDS ANALYSIS

Three questions were asked of all respondents:

1. What systems and support should research provide to help you integrate fire into land-use planning?

2. What degree of accuracy and resolution do you need now? In the future?

3. When the RD&A is developing processes and procedures, would you have the time to respond and provide inputs? Do you want to be involved? How much?

Responses were noted and tape recorded and subsequently categorized and summarized.

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[1]U.S. Department of Agriculture, Forest Service. 1973. Fire in multiple use management. Research development and application program charter. U.S. Dep. Agric. For. Serv., Intermt. For. and Range Exp. Stn., Ogden, Utah.

[2]Barney, Richard J. 1976. Land use planning--fire management relationships and needs in the U.S. Forest Service. Ph.D. Diss., Mich. State Univ. 244 p.

[3]Gerlach, Fredick L. 1974. An examination of forest fire control information systems and remote sensing application. Final Rep. (Draft) Univ. Mont., Missoula, 79 p.

SAMPLE SIZE

Management functions at each organizational level were sampled, using at least one respondent, as manpower availability permitted. Twenty percent of all national forest headquarters were sampled randomly. Ten percent of all the ranger districts were sampled randomly on a national basis. A minimum sample was one interviewee regardless of function per sample category and all available respondents were utilized. Appendixes A and B list locations selected. The sample was then reduced to include only the western regions, forests, and districts, including Alaska.

Sample Description

Participants.--Sixty-eight locations were visited, including 7 regional headquarters, 15 forest headquarters, and 46 ranger districts. In each of the regions, sample stops ranged from a low of 2 in Region 10 and a high of 14 in Region 4. The number of individuals encountered at any one of these stops ranged from 1 respondent on a small ranger district, to 14 respondents at a regional and a forest headquarters. General distributions by region for various sample attributes are shown in table 1. The number of respondents per stop averaged from 3.8 to 8.5 by region. The average for personnel per stop for the entire study was 5.2 individuals. A total of 355 respondents were interviewed at the 68 locations visited.

Geographic distribution.--Based on the land area in each region, the overall acres per stop was about 2 million acres, with some variation for Regions 5 and 10. By-and-large, however, the distribution based on land ownership appeared to be representative.

Table 1.--*Region size and sample relationships*

Region	Acreage[1]	Sample[2] stops	Acres per stop	Personnel contacted	Average personnel per stop	Personnel contacted (percent of totals)
1	26,138,941	10	2,613,894	47	4.7	13
2	21,936,820	9	2,437,424	34	3.8	10
3	20,756,119	10	2,075,612	60	6.0	17
4	31,125,801	14	2,223,271	61	4.3	17
5	19,437,988	13	1,495,229	89	6.8	25
6	23,344,264	10	2,334,426	47	4.7	13
10	20,715,704	2	10,357,852	17	8.5	5
Total or average		68	--	355	5.2	100

[1]USDA Forest Service. 1974. National Forest System areas as of June 30, 1974. U.S. Gov. Printing Office, Washington, D. C., 38 p.
[2]For detailed locations see Appendixes A and B.

The spatial distribution of the random sample also appeared to be representative. Figure 1 illustrates the sample stops and their distribution within each region. The sample did give a good geographical distribution within each region and throughout the ownership pattern; coverage was good both east and west, and north and south. Districts with both heavy and light timber and range workloads were surveyed.

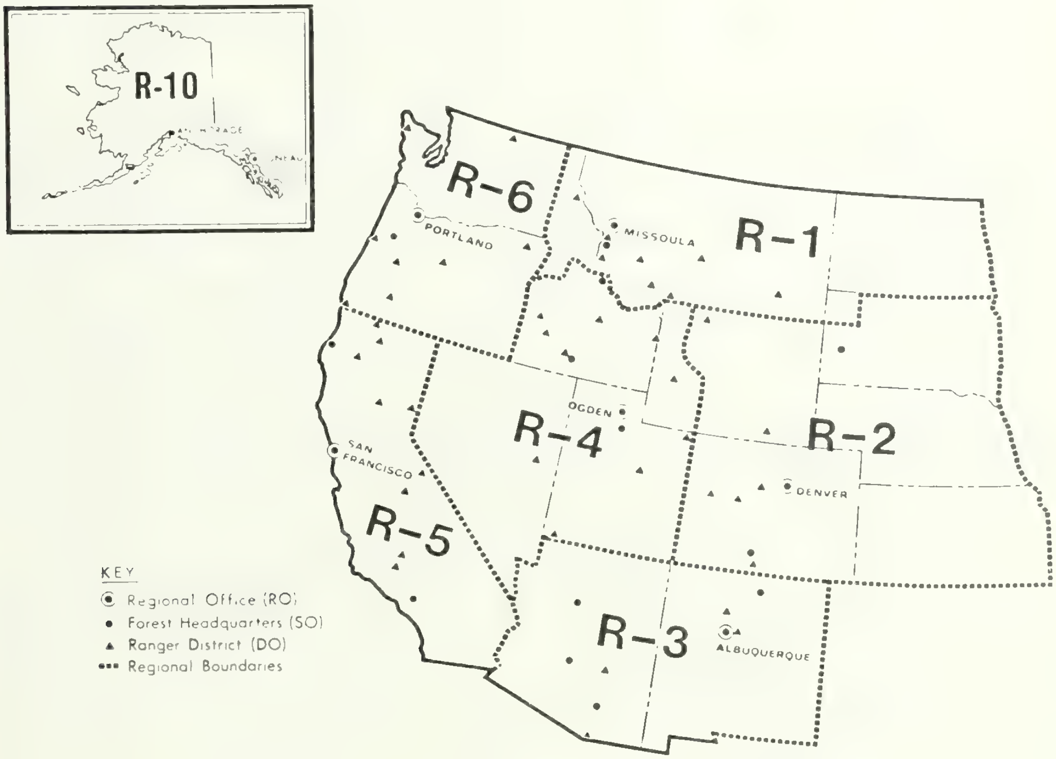

Figure 1.--Locations of managment interviews.

Respondent characteristics.--Respondents constituted a cross section of Forest Service personnel. Because this part of the study was dependent upon personnel availability and interest, result were gratifying. The distribution of positions was representative not only of total numbers, but also of each organizational level (table 2). Fire management might be overrepresented; however, because this was a fire and land-use planning study, this was expected.

Table 2.--*Summary of respondent characteristics by organizational level*

	Level			
Characteristics	Regional office	Forest office	District office	Total
Position				
Supervisor or ranger	0	9	42	50
Timber	7	13	36	56
Water	6	9	0	15
Lands	3	9	21	33
Recreation	5	8	15	28
Wildlife	5	7	3	15
Fire management	13	16	40	69
Planning	8	14	5	27
State and Private Forestry	6	0	0	6
Other	6	23	23	52
Service time (average)	20.8	15.1	13.8	15.4
Position time (average)	3.9	4.3	4.2	4.1
Education (average)	16.5	16.2	15.2	15.7

Table 3 lists individuals who listed current position as "Other." Some of the respondents could have selected existing categories, but they were allowed to list themselves as they wished.

Table 3.--*Respondent positions specified in the category "other"*

Specified position	Number
Adminstrative officer	1
Botanist	1
Deputy forest supervisor	2
Development forester	1
Drafting/planning	1
Ecologist	1
Engineer	8
Environment services	1
Fuel management specialist	1
Information and education	1
Lands	[illegible]
Landscape architect	5
Minerals	1
Plans and other resources	1
Public information officer	2
Recreation and lands	1
Resource forester	8
Silviculturist	1
Soil scientist	1
Technician	2
Total	50

Discrepancies in totals are a result of improperly completed form headings.

Average service time and time in current position were generally similar for each region. The time in service increased with the organizational level, as expected. Educational level also rises with the level in the organizational hierarchy. Fire management personnel were compared with others using all data. In this case, the service time and position time went up slightly for fire personnel. Educational levels were lower for fire control personnel. Such a response was expected since many fire management specialists have worked their way up in the organization through the technician rather than the professional career ladder.

The overall sample provides not only a geographically well-distributed grouping, but also a very satisfactory internal-position representation. It would be difficult to make many improvements at the same sampling intensity.

PLANNING NEEDS

The initial question was: "What kinds of systems and support should research provide to help you integrate fire into land-use planning?" The following summary ranks, in order of frequency, responses falling into one of 12 categories. Differences between the top five and six groups are quite small, however, and perhaps should be considered of equal importance.

Category 1.--Communications and Technology Transfer. The responses repeated most often include state-of-the-art publications, "how to" material, and on-the-ground consultations. The "how to" publication that would guide personnel at all levels through specific steps was of general interest.

Although some state-of-the-art publications have been developed, respondents were concerned about the length and breadth of these documents. Many respondents thought that these publications should be much simpler or else include a summary that would highlight the key findings. There also was a desire to have researchers' comments on the accuracy and applicability of information.

A need for on-the-ground consultation with researchers was indicated. This includes field observations and assistance by subject-matter specialists. Field personnel suggested that research would be more relevant if researchers spent more time in the field.

Respondents want to know the current status of research underway at the various research facilities throughout the country and when results will be available.

Category 2.--Economic evaluation, benefit-cost ratios, trade-offs, alternative evaluations, value system. Most responses in this category were prompted by the need to develop, maintain, and defend benefit-cost ratios of fire-related management activities, including slash disposal, fire control, and fuel management. Part of this request was undoubtly tied to NEPA and RPA; however, there was a strong desire for assistance to develop alternatives, evaluate them, and defend the eventual choice. Field personnel wanted to be able to determine odds for the success of different management strategies, various trade-offs, values that might be foregone, and benefit-cost values. Field personnel want better systems to determine values of the various resources and management activities.

The necessity for and level of fire control activities undertaken in certain situations was questioned. Personnel want benefit-cost and trade-off information to justify not taking aggressive suppression action in some situations.

Category 3.--Prescribed burning, fire use, smoke management. There is strong interest in using fire in management activities in the western regions. There is a need to know how to prepare specific prescriptions for vegetative manipulation to meet management objectives. There is a need for procedures to evaluate prescribed burning and determine if the objectives were met. Potential applications for prescribed burning are broad, ranging from understory burning and type conversion to range enhancement and management.

In every region visited, there was keen interest in using fire as a management tool. Some of the reluctance to do so evolved from a lack of confidence in meeting objectives. There seemed to be more confidence in the ability to keep fires within certain designated boundaries; respondents believed, however, that they should be able to manage resources using fire in a broader context than hazard reduction. In areas where air pollution is an issue, questions were raised about smoke and smoke management. If managers are to continue using fire and increase its use, they must be able to manage smoke.

Use and application of fire in all aspects of management needs to be explored. Basically, respondents want information on the entire array of fire management potentials including smoke management. Apparently, managers in the West are eager to use fire for purposes other than hazard reduction.

Category 4.--Management practices, fire-related ecosystems, trade-off relationships. Although category 4 is a "catchall," some very important concerns were voiced by all levels of the organization. For example, respondents wanted better guidance. They wanted more direction on how much detail is needed for the various land-use planning levels. They need clarification of the relationship between land-use planning and fire management. More basic, however, was the need to clarify the objectives of land-use planning itself. People at all levels indicated the need for better direction on land-use planning from the top down, particularly organizational objectives. There is a need to clarify policy and direction regarding fire and its role in the planning system. Respondents want more uniformity of planning systems and procedures.

Many other management-related problems were put in this category, including how to get better technical support from staff specialists who must function as subject-matter experts and information needs can vary with management situations. What tolerances (losses) are acceptable for the various management activities? Evaluation procedures are needed for planning not only fire elements, but all elements, in terms of their role in the planning process. What are the impacts of resource development and fire activities? Other responses indicate the need for getting people to think of the system as a whole and not as fragments. Where is fire an appropriate management tool and where can we *not* tolerate it? We need alternatives to fire. We must be able to link silvicultural practices, logging prescriptions, and fire as well as other management activities. We need to know how much input from any activity is necessary to make management and allocation decisions. We must understand man's effect on the fire environment.

Category 5.--Fire effects, including control effects. This category is related to category 12; however, it is more specific.

Responses indicated a need to understand more thoroughly the effects of fire--primary, secondary, direct, and indirect. Respondents want to be able to evaluate not only the impact of a fire but also the potential or actual impact of fire suppression on the overall land-management objectives. There is a need to go beyond the first-level effects of fire and predict secondary and tertiary effects. There is a need to evaluate the effects of fire and also to evaluate the impacts of land-management activities on fire-management alternatives, using a universal scale and common language.

Because of legislative requirements, "fire effects" interpretations and predictions need to address potential changes in water quality relative to vegetation burned and intensity of burn. We need to know impacts or potential impacts on smoke and air quality. More specific information is needed on fire intensity/site productivity relationships. Managers also want to know the organism's activity, small animal populations, and their dynamics.

Projections of fire effects must not only be for a short term of 5 to 10 years, but extend further into the ecosystem rotation. Nutrient loss or gain, relative to multiple burns, must be explained along with an explanation and understanding of other physical site changes resulting from fire. Not only is it important to understand the effects of fire in specific ecosystems and site situations, we must also understand the effects of fire exclusion.

Category 6.--Fire management, fire control, fire behavior, fire danger rating, etc. Concerns ranged from how to improve presuppression, to the need for better application of the National Fire Danger Rating System. Respondents pointed out the need to determine and predict if protection can be provided for specific management alternatives. If protection can be provided, how can costs and effectiveness of the system be evaluated? There is a need to clarify the relationship between land-use planning and fire-management planning itself. Along this same line, the fire organization should respond positively to the land-use planning process.

Obviously, tools and processes are needed to tie fire-management planning more closely into the total resource planning process. Personnel must be trained to insure that fire-management concepts are understood.

Fire protection, prevention, and the social impact of fire were identified as areas of weakness. More specifically, managers want to know how fire can become accepted as a management tool in the Western United States to the same degree that it has been accepted in the South and Southeast. Managers want a simple checklist for land-use planning and how fire fits into alternatives so that important items are not to be left out of plans.

Category 7.--Information storage and retrieval systems and data. Interest in information storage and retrieval systems ranged from general and research literature to very specific, site-compartment data on fire history, vegetative typing, wildlife inventories, timber inventories, and so on, for making management decisions. Information and retrieval systems should be computerized. The data base should also be set up with nationwide standards to insure commonality among Forest Service regions. Information and retrieval should be affordable and usable by local practitioners without hiring data systems specialists. Respondents indicated that a catalog or a summary of information and retrieval systems presently available and accessible would be worthwhile.

Category 8.--Fuel prediction and inventory procedures, fuel management. The eighth category did not rank as high as anticipated, considering current Service-wide emphasis on fuel management. Basically all levels in the western regions wanted to know how to go about fuels management. How do we classify fuels? Respondents indicated a need for nutrient-cycling information related to various aspects of fuel management. They indicated a need for information on the effects of various fuel reductions in ecosystems on small-mammal populations.

Managers want researchers to develop simpler methods to measure and evaluate fuels. They need to predict additional fuel loads resulting from management activities. Photo keys or similar method were mentioned as possibilities. Fuel-loading additions must also be related to fire potential on the given site. The economics of fuel management were also mentioned. Respondents wanted information on the relationship between fuel increases and changes in hazard and risk. Can a system be developed so that fuel information and other resource inventory data are gathered at the same time?

Category 9.--Feedback, evaluation, review procedures, and processes. Respondents expressed a strong need to know what research is in progress. There is a need for periodic updates of material; respondents were generally unaware of research activities until published results appeared. Respondents at all management levels wanted more input in the planning and development of research projects. This concern was particularly apparent at the ranger district level.

Respondents wanted to know if new research-developed procedures really worked and, if so, how well and what were some of the ramifications of implementing them in the field. The implication seems to be that research leaves the job once the results are published and does not follow through to see if modifications are necessary. There was strong support to tie research to field activities and problems. There was a definite criticism of research that is not problem oriented.

The need to get research results on the ground was emphasized. Suggestions included simple 1- and 2- page summary publications, training programs, semminars, and on-the-ground consultations. One individual requested a national list of Forest Service researchers, as well as an area list, with notations of the scientist's specialty. The list would assist field personnel in contacting researchers for help in answering questions on specific publications of field problems. There is an obvious, overriding need to improve communication between the researchers and the practitioner to minimize doubt, distrust, and lack of communication.

Category 10.--Computer hardware, software, analysis, and display procedures. This category is closely allied with information and retrieval systems. Field personnel expressed strong interest in the use of computer software to assist them in management activities. Here, as in the previous category, there is need for catalogs of available computer programs with commentary as to the availability, types of data required, input-output costs, reliability, etc. Many voiced the concern that often the available computer material is too costly for normal operations and that office calculations (using desk-top calculators and computers) could be done in less time than some of the computerized operations.

Respondents were interested in computerized procedures for land-use planning and fire management input. Computer systems must be usable by field personnel. Respondents recognize that the analysis-display capabilities of the computer would be helpful in evaluating management alternatives. They generally agree that computerized planning procedures are here and will be indispensible in the near future.

Category 11.--Hazard evaluation, fire probabilities. This category received minor attention compared to the others. Nevertheless, a need was expressed to determine how to measure existing hazard, much of which involves fuels produced from management activities. How do you determine "moderate resistance to control"? In a given management situation, is slash going to be a problem; if so, how much and for how long? What are the probabilities of fire occurring in slash versus nonslash areas? How can we identify hazard levels and how can we determine what effect they will have on our ability to meet management objectives?

Can we predict an increased hazard resulting from management activities? Is the magnitude of increase predictible? Can guidelines be developed to assist in making these predictions? A strong voice was raised for arriving at a standard for "living with fire." For example, de we treat slash, or under what conditions can we assume the risks if it is left untreated? All these issues center around the necessity to evaluate hazard and establish probabilities of fire occurrence.

Category 12.--The role of fire, fire ecology. The demand for specific information in fire ecology had the lowest priority. Perhaps field personnel believe they have a general understanding of the ecological situation.

Respondents showed interest in obtaining specific information on fire ecology and the role of fire in various ecosystems. Some individuals wanted to know how they might maintain various vegetative types by periodic burning. Respondents expressed a need to understand the role of fire in the various management systems at their disposal. A specific need was voiced by individuals in the Intermountain Region for a better definition of succession following fire, based on prefire habitat types and prefire land types. In this general area, a need was expressed to relate fire intensity and the probability of the type od succession expected.

ACCURACY REQUIREMENTS

The second question asked was: "What degree of accuracy and resolution do you need now? What accuracy would you like eventually?" The first question proved difficult to answer, the second question even more so. The major point made by respondents at all levels was that any improvement in accuracy over what we have today would be helpful. Respondents indicated that the 99 percent accuracy the researcher often wants is well beyond their needs and their ability to utilize in the field.

The district level response varied between 51 percent up to 99 percent for special situations; but the majority said that 60 to 80 percent accuracy would be well ahead of where they are now. Respondents realized that accuracy requirements are site-specific and would vary with the situation. Some areas and some conditions require much more accuracy or probability of success than others. The general "forgiveness" of many of the ecosystems being manipulated in our management practices helps cover up some of the low-accuracy applications. Respondents seem to be saying that improving success by 5 or 10 percent would be a giant step forward. Eventually, of course, they would like to make more decisions with a greater probability of success. However, they are well aware of the fact that they will continue to make decisions regardless of whether or not there is more research information.

The need to keep resolution levels in pace with the intended application was indicated. Respondents are more than willing to accept first-approximation information that might come from "quick-and-dirty" studies. They do want some indication of how accurate and how applicable the information is and what the chances for success are in a specific situation. They believe that it is their job to determine what to do from that point forward because they, not the researchers, are responsible for the land. Respondents also believe that once they begin refining management objectives, the need for more specific and precise information becomes apparent.

In summary, field personnel say they need to get existing information into the system. They need to be professional enough to extend that information as far as their expertise will allow for the situation at hand. They will tell research when they need more specific information. They will indicate when they cannot do something because the information is not adequate. They do, however, need some idea of the reliability of the information. They would like to have some indication of how far the information can be extrapolated for the situation at hand.

REVIEW, RESPONSE, AND LITERATURE

The final question was: "When the RD&A program is developing processes and procedures, would you have time to respond and provide input? Do you want to be involved? How much?" All interviewees said they must keep abreast with what research is doing.

They must participate and criticize. The only reservations concerned time and the need to limit inputs to a few pointed remarks. If asked to review materials, respondents felt they could provide marginal notes and some assessment, but not in-depth reviews. This was one of the important outcomes of the study. It illustrated that we have not fully utilized this intensity. Respondents sincerely believed that they had an obligation to respond. In short, the answer to the basic question was an unequivoca "Yes, we want to be involved and we will be involved as much as our other tasks allow us to be."

SUMMARY

The question asked all respondents concerning their needs for integrating fire into land-use planning evoked a wide array of responses. Because of the breadth of responses, it was necessary to group them into 12 categories, ranging from state-of-the-art and "how to" papers and consultations to the desire for feedback, evaluations, and review mechanisms. Throughout the entire sample, many of the responses were repeated. The compilation provides an indicator for future research direction. These responses also help sharpen the focus on current research and management.

The broad category of communications and technology transfer rated high as a need to integrate fire management into the land-use planning process. Basic methods suggested included state-of-the-art papers, "how to" publications, and on-the-ground consultation. Economics, benefit-cost ratios, trade-off procedures, and value systems comprised the second most important need. The major concern centered around the need to develop, maintain, and defend benefit-cost ratio material of fire-related management activities. Third, the use and application of fire in all aspects of management activities needs to be broadened and explored. Some of the more specific concerns include prescription preparation and execution, smoke management, and postfire evaluation. Under the fourth-ranked category (management practices...) personnel wanted better overall guidance from the top down, including more specific process advice and clarification of land-use planning objectives. In the fifth-ranked position, fire effects, quantification became important. Broad-based needs were expressed to put values on fire effects (good or bad) and on the effects of fire control action.

Based on the study results, it appears more specific direction is warranted. Processes for getting the job done must be developed and spelled out for general use. A strong, universal data base is also a must. Training in planning philosophy and process would go a long way toward resolving some of the questions raised. Much is known and can be brought to bear on the issues, but technology transfer mechanisms must be developed, improved, and implemented. Field personnel must also be better able to define the problems, not the symptoms for research.

Replies to what kinds of accuracy and resolution are needed now and in the future also evoked a range of answers. The major point made was that any improvement in accuracy would be helpful. Accuracy requirements would necessarily have to be site and situation specific. Respondents need information now but would like some measure of its applicability. How far can it be extrapolated; what are the probabilities of success of failure?

All respondents indicated a desire to become involved in the development of procedures for the RD&A program. They feel obligated to respond, contingent upon time available and interest in the specific topic.

As a direct result of this study, a wide audience in the Forest Service now has a clearer understanding of the purpose, scope, and intent of the RD&A Program. More than 300 field personnel have come face-to-face with research on a current, pressing, and practical issue. These meetings provided important communication and feedback for both sides. Finally, universal commitment to help review RD&A material provides widespread and representative contact with fieldmen.

APPENDIX A:
REGIONS AND FORESTS SELECTED FOR INTERVIEWS

APPENDIX A

Regions and Forests Selected for Interviews

Regions	Natural Forests
1	Bitterroot*
2	Black Hills Rio Grande*
3	Carson Cibola* Coronado* Kaibab Tonto
4	Salmon Sawtooth Wasatch
5	Angeles Six Rivers
6	Siuslaw*
10	Chugach

*Indicates one or more districts on the forest also were sampled.

APPENDIX B:
RANGER DISTRICTS SELECTED FOR INTERVIEWS

APPENDIX B

Ranger Districts Selected for Interviews

Regions	National Forests	Ranger Districts
1	Beaverhead	Madison
	Bitterroot*	Stevensville
		West Fork
	Custer	Fort Howes
	Deerlodge	Butte
	Gallatin	Gardiner
	Idaho Panhandle	Wallace
	Lewis and Clark	Musselshell
2	Grand Mesa-Uncompahgre	Collbran
	Medicine Bow	Centennial
	Rio Grande*	Conejos
	Shoshone	Wapiti
	White River	Aspen
		Dillon
3	Cibola*	Sandia
	Coronado*	Nogales
	Santa Fe	Jemez
	Tonto*	Globe
4	Ashley	Flaming Gorge
	Boise	Lowman
		Mountain Home
	Bridger-Teton	Big Piney
	Challis	Lost River
	Dixie	Pine Valley
	Humboldt	Ely
		Jarbridge
	Manti-LaSal	Price
	Targhee	Teton Basin
5	Inyo	Mono Lake
	Klamath	Oak Knoll
	Los Padres	Mt. Pinos
	Plumas	Oroville
	Sequoia	Greenhorn
	Shasta-Trinity	Yolla Bolla
		Weaverville
		Sacramento
	Sierra	Minarets
	Tahoe	Sierraville
6	Ochoco	Big Summit
	Okanogan	Tonasket
	Olympic	Soleduck
	Rogue River	Prospect
	Siskiyou	Chetco
	Siuslaw*	Waldport
	Wallow-Whitman	Bear-Sleds
	Willamette	Lowell
10	None	

*Indicates the forest headquarters was also sampled.

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Three questions regarding fire research needs were asked of 355 respondents at 68 western USDA Forest Service locations. Responses have been analyzed, summarized, and [illegible]. Results provide guidance for defining and setting priorities in wildfire research in the western regions of the USDA Forest Service.

KEYWORDS: wildfire, research needs, problem definition.

Barney, Richard J.
1979. Wildland Fire Research Needs in the West: Forest Service Managers' Views. USDA Forest Serv. Gen. Tech. Rep. INT-63, 15 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Three questions regarding fire research needs were asked of 355 respondents at 68 western USDA Forest Service locations. Responses have been analyzed, summarized, and [illegible]. Results provide guidance for defining and setting priorities in wildfire research in the western regions of the USDA Forest Service.

KEYWORDS: wildfire, research needs, problem definition.

Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

- Billings, Montana
- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with University of Montana)
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RFACE ENVIRONMENT & MINING
SEAM
FOREST SERVICE PROGRAM

USER GUIDE to VEGETATION

Mining and Reclamation in the West

U.S.D.A. FOREST SERVICE
GENERAL TECHNICAL REPORT INT-64
INTERMOUNTAIN FOREST AND RANGE
EXPERIMENT STATION
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

RESEARCH SUMMARY

The vegetation specialist working on mined land must be aware of potential impacts of mining, as well as reclamation techniques available to him. This guide covers major points of concern to the vegetation specialist involved in planning for reclamation of mined land, including: exploration and baseline data; species selection; plant materials; site preparation; planting methods; cultural treatments; and post-mining management plan and monitoring.

Information is presented in a question/rule/discussion format, and includes supporting graphic material, notes on additional sources of information, a glossary, and an index.

ACKNOWLEDGMENTS

The contents of this guide are based on presentations and discussions during the Surface Environment and Mining (SEAM) sponsored Vegetation Workshop, February 21-23, 1979, Denver, Colorado. Credit is due all attendees and presenters for their input. Those who attended are listed in appendix B. In addition, major contributors are listed under chapter titles as appropriate.

A special note of thanks is extended to Earl F. Aldon, Ardell J. Bjugstad, Paul E. Packer, and Robert Partido, members of the cadre which planned the workshop. The workshop program coordinator was Edwin R. Browning (SEAM) and the technical adviser was Grant Davis (SEAM).

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USER GUIDE TO VEGETATION MINING AND RECLAMATION IN THE WEST

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401

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INTRODUCTION

ERAL AND NONMINERAL RESOURCES

adequate, reliable supply of minerals is ial to the economy and security of the d States, since minerals provide the physi- sis for almost all activities of U. S. citizens. imports can satisfy an important part of ountry's minerals demands, they make the vulnerable to the economic and political ons of foreign countries. Thus, the mineral its within the U. S. are a most important of this nation's supply.

ubstantial portion of the domestic miner- pply presently comes from lands managed e Federal Government. Federal lands con- majority of the metallic minerals, as well jor resources of coal, oil shale, geothermal , uranium, and oil and gas. These same al lands, however, also contain valuable ineral resources, including timber, forage, wildlife, scenic landforms, and wilderness. overnment's holdings of such resources are mong the most significant in the world.

ile it is clearly in the national interest to e for the identification and production of ineral resources on Federal land, it is also ary to provide for a sustained high-level t of the various renewable resources on and. Thus, the demand for mineral de- nent must be balanced against the demand enewable resources and the land- ement agency's responsibility to reason- protect the environment affected by l-related operations.

MINERALS IN THE
l-MANAGEMENT PLANNING PROCESS

h Forest Service, as one of the agencies sible for Federal land management, has a ly sophisticated planning program for the ment of nonmineral resources on land under its jurisdiction. Historically, however, the Forest Service's land-management and planning systems have treated minerals as a distinct category outside of the mainstream of the land-management planning process. There are two basic reasons for this separation:

1. The mining and mineral leasing laws have tended to make mineral activity the preferred use on any Federal land open to such activity. The thinking has been that on lands open to mineral activity, mineral development will generally override the designated primary nonmineral uses.

2. Planning for use of the mineral and nonmineral resources is complicated considerably by the difficulties of identifying and estimating the value of mineral resources. Mineral resources can be found only through costly and risky exploration. Therefore, land-management planning has tended to concentrate, at least until a mineral discovery is made, on the surface resource potential of the land.

The long-standing premise that mineral activity is always the most valuable use of a tract of land is increasingly being challenged. Many mineral deposits being discovered today are of lower grade, located at greater depths, and are therefore more expensive to find and mine than the high grade surface deposits formerly developed. Another significant factor is that nonmineral surface resources are now also considered to be scarce, and their value has increased accordingly.

Hence, when all the mineral and nonmineral values are weighed for a particular proposal at a specific location, the value of the mineral resources may be outweighed by the value of the nonmineral resources. The process of weighing values usually occurs in an Environmental Assessment required by the National Environmental Policy Act of 1969 (NEPA)(P.L.91-190), and is basic to determining the proper mix of uses for any given land area.

Given this situation of mineral and nonmineral values on the same tract of Federal land, decisions as to the proper use of a particular tract of land will always involve balancing the values of mineral and nonmineral resources. If this balancing is to be done in a reasonable manner, adequate information and analysis of all values are needed.

BACKGROUND: THE FORMATION AND MISSION OF SEAM

Realizing the complexity of such decisions, in 1973, the Forest Service chartered the Surface Environment and Mining program (SEAM) to coordinate research, development, and application related to land impacts resulting from minerals exploration and development in the West. From 1973 to 1979, SEAM sponsored more than 150 research and development projects. Together, the projects have greatly added to the body of knowledge surrounding the management of land in mineralized areas. (For purposes of this discussion, mineralized areas are defined as those areas that have some potential for mining.)

To get this knowledge to the specialists in the field in a form they could readily use, SEAM brought together researchers and users from industry, Federal agencies, and the academic community to share their practical knowledge and study results in a series of workshops. The information presented at these workshops is organized into five user guides. Each guide focuses on a specific discipline involved in managing surface resources that may be affected by mineral activities and is written for specialists in these disciplines. The guides will also be of use to land managers, land planners, and other specialists since many activities related to minerals-area management demand that a variety of skills be applied to achieve an integrated approach.

In addition to the User Guide to Vegetation, guides have been written for soils, hydrology, engineering, and sociology and economics. Cross-referencing among these guides is provided in the index. A handbook for minerals specialists has also been written. A handbook for managers will provide a general overview o ministrative considerations surrounding mi commodities commonly explored for anc veloped on national forest lands administere the Forest Service. Concurrent with the velopment of the SEAM user guides, a U handbook on visual management related to ing and reclamation, entitled "Mining," press as volume 2 of the National Forest L scape Management Series. A guide for the life specialty is also planned. All guides wi updated periodically to keep them current research findings.

The purpose of the guides is to help sp ists more clearly understand their role in mi exploration and development activities by lining some of the major considerations must address to insure that such activities grate with land-management plans; that im are mitigated to a reasonable degree; and reclamation meets state-of-the-art perform standards. Perhaps by using these guides common starting point, those involved in m als management can more easily work tog toward achieving these common goals: (1 propriate consideration of minerals value land-management planning; (2) protectio surface resources during mining activities; (3) reclamation of surface-mined land to a ductive use.

HOW TO USE THIS GUIDE

The chapters of this guide cover topics concern the vegetation specialist during land-management planning and any subseq minerals activity. Within each chapter, m topics will be addressed in this way:

• Considerations: These are the questions vegetation specialist should ask about topic.

• Rules: These general statements answe questions and direct the vegetation speci toward the type of site-specific information land manager may need to make decisions. R are set in italic type.

Discussions: The discussions explain the ning behind the rules and in some cases give fic examples of how the rules are applied.

Exceptions: Exceptions to various state- s are given where applicable.

Additional Information: Here the reader find basic references to further information e topic discussed.

e aim of this format is to help define the of the vegetation specialist in minerals gement. The guide is not intended to be a okbook" on rehabilitation techniques. er, it is intended to set up a logical thought ess based on a question/answer approach. an approach allows for flexibility, elimi- unnecessary data gathering, helps simplify ical decisionmaking, and allows for a ematic documentation of the decision- ng process. We hope that this organization aterial will make the guides equally useful ers in industry, Federal and State agencies, he academic community.

e role of the Forest Service staff is illus- d in table 1, "Stages of Mineral Exploration Development Activities," and table 2, es of Forest Service Specialists in Minerals ities," which follow this introduction. As will note, the Forest Service vegetation alist will advise, review, and monitor. For ple, although planting takes place during mation, the vegetation specialist will review plans when the operating plan is submitted to development and, if necessary, suggest ons to the plan to improve reclamation po- ls. Then, during mining and reclamation, orest Service specialist will monitor these ties according to the approved operating In this way, the effects of the development e managed in a proactive, rather than re- mode. In other words, rather than react- crises, the vegetation specialist will be part e forest's interdisciplinary (ID) team from time land-management planning begins. if and when mineral activities occur, the will have foreseen potential problems and ave determined general rehabilitation ob- es in advance.

th land-management planning, in its broader application, and site-specific operational planning for mineral activities on National Forest System lands require the full range of interdisciplinary efforts so that information on both the mineral and nonmineral values can be presented to the decisionmaker in an integrated manner. The interdisciplinary approach to planning is uniquely suited to giving the best available assessment of the spectrum of opportunities and problems of managing surface resources that may be affected by mineral-related operations and the requirements needed for reasonable protection of nonmineral resources. Soils, vegetation, hydrology, topography, geology, wildlife, climate, and social and economic information are some of the factors that must be considered by the ID team.

Land management and planning must always proceed on the basis of existing information. In the case of mineral resources, this will almost always be difficult because the mineral resources are hidden beneath the surface and information is provided in increments as exploration proceeds. One of the principal goals of Federal land management, therefore, should be to improve such management by obtaining better mineral-resource information and integrating it into the decisionmaking processes.

When using this guide, the reader should keep in mind that, for the most part, the information is concerned with scientific considerations. While other factors, particularly cost and legal constraints, are a crucial part of the planning process, discussion of these aspects is limited here.

One final note: Successful rehabilitation is as much an art as a science. To clarify specific points or to keep up with new developments, readers are urged to contact the researchers who contributed to this guide or their regional reclamation specialists.

Additional Information:

For more information on the mining process, refer to "Anatomy of a Mine," USDA For. Serv. Gen. Tech. Rep. INT-35. 1977. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Table 1. — *Stages of mineral exploration and development activities*[1]

Prospecting	Exploration	Feasibility studies/operating plan
A. Administrative Action No administrative action required; however, some evidence of mineralization or a hunch	A. Administrative Action Permit/Lease Notice of intent from miner (for certain commodities, may also serve as operating plan if there is minimal surface disturbance) Exploration license EA may be necessary See Handbook for Land Managers (in press) for variation within commodities	A. Administrative Action Submission of necessary permits (E etc.) and operating plan—see Han for Land Managers (in press) for within commodities
B. Activities Literature search Geological inference Evaluation of existing data Research on rights to land/ minerals	B. Activities More intensive literature search Access road construction On-site testing and evaluation of data— geological, geochemical, geophysical, drilling, sampling, shaft sinking Seismic activity Acquiring land/mineral rights Rehabilitation of exploration impacts Environmental and socioeconomic studies	B. Activities Feasibility studies Grade and size of deposit Cost of mining and rehabilitation Market Fiscal Technical studies—mine design Environmental and socioeconomic (if not done during exploration) Decision to proceed with developm Preparation of operating plan inclu rehabilitation program and end u Ordering of equipment
C. Environmental Impacts Minimal, if any	C. Environmental Impacts Roads Drill holes Drill pads Dozer holes Exploration camps	C. Environmental Impacts Generally none at this stage
D. Tasks for the Vegetation Specialist None at this point	D. Tasks for the Vegetation Specialist Review of plans to reclaim land impacted by exploration Review and assist in vegetation aspects of environmental studies	D. Tasks for the Vegetation Specialist Review adequacy of operating plan Reclamation Program— species selection plant materials site preparation planting methods cultural treatments Monitoring/retreatment program fo vegetation Vegetation aspects of end use

[1] The various phases have considerable overlap. The material provided for each phase is illustrative, not complete, and con variation is found by commodity. The existence of a forest plan is assumed. Tasks (D) are primarily input from a land-man agency's vegetation specialist. For purposes of discussion, the terms reclamation and rehabilitation are used interchangeably, an includes oil and gas activities.

lopment[2]	Mining/reclamation	Postmining
dministrative Action pproval of necessary operating plan	**A. Administrative Action** No administrative action required. Mining overlaps with development and reclamation overlaps with mining; reclamation of previously mined areas occurs concurrently with new mining as stipulated in operating plan Any changes in operating plan	**A. Administrative Action** Release of reclamation bond
ctivities curing of financing ore extensive testing and definition of the mineral nstruction of transportation routes and utilities nstruction of mine and processing plant (facilities, water supply, etc.) nstruction of waste deposits ntinued evaluation of data ange mining plan if necessary	**B. Activities** Extraction of mineral Processing of mineral Depositing wastes Operation of transportation systems Rehabilitation Monitoring for any changes in biological and physical environment Amend mining and rehabilitation plan if necessary	**B. Activities** Surface owner manages land after bond release Monitoring for any changes in biological and physical environment Management and maintenance for end-use objective
nvironmental Impacts ine ocessing plant aste dumps ansportation and access routes ilities creased population resulting from construction	**C. Environmental Impacts** Impacts directly related to operational aspects of mining; impacts are strongly affected by commodity mined and type of operation	**C. Environmental Impacts** Directly related to management and maintenance activities
asks for the Vegetation pecialist onitor vegetation impacts and activities for conformance to operating plan. Advise on plan revisions when necessary	**D. Tasks for the Vegetation Specialist** Monitor vegetation impacts and activities for conformance to operating plan. Advise on plan revisions when necessary Advise from a vegetation standpoint on release of reclamation bond	**D. Tasks for the Vegetation Specialist** Monitor any continued impacts on vegetation Manage vegetation for end-use objective

elopment is herein defined as the phase which begins after the right to mine has been established.

Table 2.—*Roles of Forest Service specialists in minerals activities*

	Prospecting	Exploration	Feasibility studies/operating plan
Vegetation specialist	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in vegetation aspects of environmental studies	Review adequacy of operating plan for: Reclamation program — species selection plant materials site preparation planting methods cultural treatments Monitoring/retreatment program for vegetation Vegetation aspects of end use
Soils scientist	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in soils aspects of environmental studies Review soils inventory progress in the the mineralized areas; if needed, recommend timely completion or upgrading	Review adequacy of operating plan for: Reclamation Program— soils surveys storage area selection materials handling plans spoils analysis plan spoils treatments spoils surfacing and erosion control Monitoring/retreatment program for soi Soils aspects of end use
Hydrologist	Establish baseline water-quality monitoring as needed according to plan	Review of plans to reclaim land impacted by exploration Review and assist in hydrologic aspects of environmental studies	Review adequacy of operating plan for: Hydrologic considerations— surface water subsurface water snow management roads impoundments mine drainage Hydrologic aspects of end use
Engineer	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in engineering aspects of environmental studies	Review adequacy of operating plan for: Engineering considerations— air pollution transportation facilities surface-mine facilities mine-waste disposal embankments tailings dams and impoundments subsidence Engineering aspects of end use
Economist	Monitor factors which affect supply and demand for minerals Make forecasts of supply and demand Predict probability	Analyze costs and benefits of alternative exploration methods Participate with the sociologist in identification of existing and emerging issues	Provide expertise in environmental analy process: issue identification decision criteria cost/benefit analysis of alternatives tradeoff and opportunity-cost evaluat Analyze effects of development on: demand for surface resources human behavioral patterns community economics
Sociologist	Identify the basic social/cultural descriptors of the affected communities Note current trends	Assist in structuring public involvement plan for appropriate: issue identification issue analysis mitigation action Identify critical trigger points from a social perspective	Provide expertise in environmental analys process: decision criteria issue identification Analyze effects of development on the cultural and political community Consider effects of alternative plans on social well-being

Development	Mining/reclamation	Postmining
Monitor vegetation impacts and activities for conformance to operating plan. Advise on plan revisions when necessary	Monitor vegetation impacts and activities for conformance to operating plan. Advise on plan revisions when necessary Advise from a vegetation standpoint on release of reclamation bond	Monitor any continued impacts on vegetation Manage vegetation for end-use objective
Monitor impacts on soils Monitor soils-related activites for conformance to operating plan. Advise on plan revisions when necessary	Monitor soils impacts and activities for conformance to operating plan. Advise on plan revisions when necessary Advise from a soils standpoint on release of reclamation bond	Monitor any continued impacts on soils Manage soils for end-use objective
Monitor impacts on hydrology	Monitor impacts on hydrology and hydrologic aspects of rehabilitation program Have hydrologic input into release of reclamation bond	Monitor any continued impacts on hydrology Manage hydrology for end-use objective
Monitor engineering-related activities for conformance to operating plan Advise on plan revisions when necessary	Advise from an engineering standpoint on release of reclamation bond	Monitor any continued impacts from engineered structures Manage structures for end-use objective
Record costs Monitor economic changes	Record costs Monitor economic changes	Monitor to determine accuracy of predictions for future use
Monitor Record changes Identify areas of individual or group stress relating to mineral activity and make recommendations to mitigate effects	Monitor Record changes	Monitor and record critical changes to establish new baseline situation

Chapter 1
EXPLORATION AND BASELINE DATA

ter Organizer: Grant Davis

r Contributor: Grant Davis

ineral exploration is the process of identify-nd investigating "targets" in order to dis- an economic mineral deposit. Exploration s with regional studies that create little or sturbance or occupation of the land. In ad-n to compiling existing geologic and photo-gic information, exploration also involves gic mapping and geochemical surveys. By ime a regional study has defined specific t areas, only a small portion of the lands ially considered is selected for more inten-study and exploratory work. At this stage, land disturbance—drilling, for example—occur.

ould a mineral deposit be found, the area nd involved is subject to more intensive ex-tory work in a tighter pattern and is ac-anied by more surface disturbance. If the ratory work locates an ore body, develop- and mining are confined to an even more zed land area. Thus, a mining company's on to explore an area for mineral deposits require the land-management agency's nnel to become involved in a more intense sis of the site than would normally occur g land-management planning.

will the vegetation specialist be involved he mining company during exploration?

e vegetation specialist will advise the land ier on the impacts that exploration may to the vegetation, and may or may not with the mining company in collecting pre-ry data on the site.

usion:

mpacts on the vegetation might include ility and soil toxicity problems or disturb-a ritical plant species stand. The vegetation specialist should work closely with the soils scientist in assessing these impacts and advising on their mitigation. In addition, if an exploration permit was required from the mining company, the vegetation specialist should review it from the aspect of the steps planned to re-vegetate the sites disturbed by exploratory activities.

During exploration, the mining company will drill to determine if the mineral resource is minable. The Forest Service should ask the mining company to provide drilling data and cores collected during exploration. Keep in mind that such information may be proprietary. Any data already gathered at this stage, however, may be helpful if and when the decision to mine is made because it could provide preliminary information on potential problems, such as toxicity or erodibility, that may be encountered later during development and mining. In addition, if exploration leads to the mining company's decision to mine the site, the timespan for collecting data may be short, and thus any data already gathered may be helpful in answering specific questions posed in the Environmental Assessment.

Does the Forest Service have access to a mining company's data?

If a mining company has collected data about a leasable mineral, the company is required to give the Forest Service certain information about such mineral deposits. A prospecting permit may require the company to supply this information. A coal license absolutely requires this information from a mining company. For locatable minerals, any information collected is considered "privileged," and the company that collected it controls access to it.

Discussion:

Because mining companies have complete control of certain information they collect dur-

ing exploration, prior data collection by the Forest Service ID team is essential. The Forest Service should have information about every mine site on its land, whether for a leasable or locatable mineral, because, in either case, it will be the responsibility of the Forest Service to insure that surface conditions are not irrevocably harmed during mining. In addition, a close working relationship between the Forest Service and the mining company, developed early in the mining process, can be beneficial to both parties since their combined effort can produce a more thorough data base.

BASELINE DATA AND THE MINING PLAN

Once exploration is complete and the mining company determines that it will mine the site, an Environmental Assessment may be in order and the formal gathering of baseline data to be included in the mining plan begins. Baseline data measure the conditions existing on the site prior to disturbance, help determine reclamation goals, and provide a basis against which reclamation success can be measured. Based on these comparisons, the mining operator may or may not be released from his bond of liability subsequent to mining and reclamation activities.

At this point, more specific information about the site may be needed to answer specific issues or management concerns identified in the planning process. This information must be scientifically sound and well documented in case it is later challenged. In addition, ID team members should coordinate their efforts so that the data collected do not overlap.

What is the role of the vegetation specialist in the collection of baseline data and approval of the mining plan?

The vegetation specialist will be specifically concerned with data needed to answer questions related to vegetation in the Environmental Assessment. He should require data sufficient to allow him to advise the lund manager whether to accept, reject, or modify a company's mining plan, based on how the plan addresses vegetative considerations. All vegetative information collected should be relevant to this objective.

Discussion:

The vegetation specialist should determ
what information is appropriate to the conc
that need to be answered, what funds are a
able for collecting the data, and who will col
it. He should require only the level of data n
ed to answer specific questions for the l
manager or to meet legal requirements.
level of data usually requires on-site studies
1) and selecting an appropriate vegetation cl
fication system to conduct the on-site stu
Vegetation classification systems vary wid
and generally the vegetation specialist can
on the system that has been in use in his a

Vegetative data generally needed incl
identification of existing vegetation on the
by species composition, its productivity
cover density, and its prior use. Native ve
introduced species, threatened and endang
plant species, animals supported by the veg
tion, yearly and seasonal variability, and
tential pest problems should also be noted.

Productivity measurements are important
cause the mining plan, or law, may state that
vegetation productivity after mining will
equal to, or greater than, it was prior to min
Productivity and cover density can be measu
using exclosures, plots, or transects. In pla
where present vegetation does not reflect
true potential or where rehabilitation goals
quire a change in vegetation types, potential p
ductivity will have to be based on soil types
determined with the help of the soils scient

In addition to analyzing productivity of
vegetation on undisturbed soils, an estimate
the productivity of the overburden strata is a
important because these materials may beco
the plant-growth medium after mining. Furt
analysis of the drilling samples will aid in t
evaluation. Past, present, and potential uses
the vegetation are also important considerati
and should be noted in the baseline data.

Information on threatened and endange
plant and animal species should be obtain
The vegetation specialist can work with the w
life specialist or consult State and Federal l
for information on such species. In addition,
should be aware of the characteristic habitats
endangered animal species. This informat
may indicate that the site to be mined is a ty
cal habitat of a threatened or endangered spe
even if the animal is not observed during b

Figure 1. On-site study plots are valuable in testing proposed revegetation techniques. (Decker Coal Mine)

data collection. If so, the site may have to eturned to the same type of vegetation after ng in order to preserve critical habitat.

consideration in baseline data collection is the season in which the data were collected cts productivity measurements, because in species are dominant at certain times of ear. In addition, any amendments added to oil may temporarily increase productivity, thus skew the accuracy of baseline pro- vity measurements.

assess potential pest problems, baseline should note whether there are noxious es in the area that might invade the site or ether potential animal pest problems exist.

ter analysis of these data, the vegetation alist should be able to advise the land nger whether to accept, reject, or modify a many's mining plan, based on how the plan drsses vegetation considerations. The vegeta- n pecialist may also be responsible for proposing options to the mining plan either alone or as a member of an ID team. The land manager can request a periodic review of the plan during which changes can be made if (1) the mining processes are unreasonably damaging vegetative resources; or (2) only preliminary baseline data are included in the mining plan.

Who collects baseline vegetative data?

Either the Forest Service or the mining company may collect the baseline data. Responsibility for data collection will be negotiated between the Forest Service and the mining company in each mining situation after the company has made the decision to mine.

Discussion:

When the mining operation will be on Forest Service land, it is the responsibility of the land manager to determine if the mining plan has an adequate baseline data design, and then if the

data are collected according to the plan.

Although it is the responsibility of the Forest Service to insure that baseline data requirements are met by operators on Forest Service land, in certain areas of the country the Forest Service is considering allowing State agencies to enforce their own State requirements on National Forest System lands because these regulations are at least as stringent as Forest Service or Federal requirements. An example is the State of Wyoming. In these situations, the Forest Service will still approve mining plans and will retain authority over Forest Service lands.

In the case of small mine operators, extensive data collection may be economically unfeasible. To aid these operators, Federal assistance can be applied for through the Small Operators Assistance Program, Office of Surface Mining, U. S. Dept. of the Interior. This program was established by the Surface Mining and Reclamation Act of 1977 (P.L. 95-87, 30 U.S.C., Secs. 1201 et seq.).

Who must gather the vegetative information for environmental assessments if they are required?

If the operation is located on national forest lands, the forest supervisor may be required to provide baseline data, in which case the vegetation specialist will probably be involved in data collection.

Discussion:

The Forest Service vegetation specialist may be actively involved in data collection, or involved only in review of the data, depending on who must supply the data. In either case, the same kind of information is needed.

Should baseline data be computerized?

If a large amount of data will be collected or an Environmental Assessment or Environmental Impact Statement is required, computerizing data may aid in easy retrieval during mi activity and postmining monitoring.

Discussion:

The decision to computerize the data sh be made before or in the early stages of the collection process. If there is going to be a l baseline requirement and an intense monito requirement throughout the mining process, option to computerize the data should be sidered.

What other activities are important consic tions during baseline studies?

The vegetation specialist should urge tl doing baseline studies to watch for arch logical resources as the site is examined. specialist should also encourage establishmen permanent study plots for use throughout mining, reclamation and postmining phases.

Discussion:

Although a trained archaeologist will conc an official paleontological or archaeological vey, all members of the team should aid in cating such objects during field studies.

Study plots will be essential throughout mining process to determine what reclamat techniques are most successful on the site.

Additional Information:

For more information on baseline stud refer to "A Systems Approach to Ecolog Baseline Studies," U.S. Dept. of the Inter Biological Services Program, Fish and Wild Service, FWS/OBS-78/21. March 1978.

For more information on a vegetation class cation system that has been developed for e systems in the Southwest, contact the USI Forest Service, Rocky Mt. For. and Range E Stn., Albuquerque, N.M.

Chapter 2
SPECIES SELECTION

pter Organizer: Ray W. Brown

or Contributors: Ray W. Brown, Kay H. y, Neil C. Frischknecht, Richard L. Hodder

\mong the first critical tasks in rehabilitating ne site is the selection of the plant species to used. The vegetation specialist must be fa- ar with both legal requirements and the -management goals affecting revegetation choose the adapted species accordingly. For nple, if the area will be reclaimed for live- k grazing, the adapted species should be table to livestock. Correct species selection be a difficult decision, but it is vital to recla- ion success because, once permanently es- ished, vegetation will provide ground cover, ice or prevent erosion, and eventually will rn the site to a usable condition.

y is proper species selection complex?

The major reason is that not all species are pted to all sites or uses, and a number of ors affect adaptability. Usually, there are y more species that are only marginally pted to a given site than are truly adapted.

ussion:

he vegetation specialist must be able to tify these adapted species because the abili- f a species or ecotype to adapt—to complete ntire life cycle and replace itself in succeed- generations—to a specific site is a key to suc- ul land rehabilitation.

xception: Nurse crops, also called com- nion crops, may be unadapted to a mine se. These plants are usually annual species tat can be planted either before or with te permanent species to temporarily stabi- lie the site and aid in the establishment of t permanent species. They are useful in certain situations when immediate stability of the land or amelioration of soil characteristics can be more effectively accomplished by including a nurse crop with the permanent planting. While some researchers have had success by planting a harsh site with a nurse crop of a species that will persist several years, other researchers have found that nurse crops are not desirable because they delay or reduce permanent seedling establishment due to their excessive competition. In these cases, researchers have been more successful by initially seeding with primary, adapted species that are capable of plant colonization. (For a further discussion of nurse crops, see chapter 6.)

Can both native and introduced species be considered adapted species?

Both introduced and native species can be successful in revegetating disturbed lands if they are adapted to the site (fig. 2). Although some State laws direct the use of native plants, most researchers agree that the term "adapted" is

Figure 2. Native species will often invade a revegetated mine site.

more appropriate to a discussion of species selection.

Discussion:

When considering introduced species, review Executive Order 11987, "Exotic Organisms." May 24, 1977.

What criteria should be considered in selecting adapted species?

Adaptability is intimately tied to the ability of a plant to complete its entire life cycle and to reproduce itself from year to year over a long period. The plant's growth form, drought resistance or tolerance to stress, mineral nutrition requirements, and reproduction characteristics are all important considerations when selecting an adapted species. Availability of seed and competition among species being planted are also important factors.

Discussion:

Species selection is complex and involves, in addition to consideration of the species itself, a trade off among many interacting factors. These include: Federal, State and local requirements; rehabilitation objectives; nature of the site; time and timing; species compatibility; mechanical limitations on planting; seed and seedling availability; maintenance after planting; and cost.

- **Legal requirements.** Laws concerning rehabilitation standards are changing rapidly. As part of planning, check Federal, State, and local regulations to make sure the species selected fulfill these requirements. State seed laws may also affect the importation of certain seeds.
- **Rehabilitation objectives.** The vegetation specialist must know what functions the plants are to serve. The species selected are heavily dependent on this answer.

For example, if the goal is to provide a wildlife habitat, a variety of grasses, forbs, shrubs, and trees may be desirable in order to provide feed, cover, and nesting for birds and animals. If other end uses, such as for crops, rangeland forage, natural beauty, or recreation are the goals, different types of species may be more appropriate.

> Exception: Regarding wildlife habitat, some land managers prefer to manage a site for one animal species, rather than to try to provide cover for a variety of anima Obviously, this simplifies the job of c termining required wildlife habitat.

Additional Information:

For more information on wildlife habitat quirements, refer to:

"Run Wild," Wildlife Research Progr USDA Forest Service, Rocky Mt. For. Range Exp. Stn., Albuquerque, N.M.

"Rehabilitation of Western Wildlife Habi A Review," prepared by the staff of the Ir tute for Land Rehabilitation, Utah State versity, Logan, Utah. Edited by Western Ene and Land-Use Team, Phillip L. Dittber Project Officer. Ft. Collins, Colo. FWS/O 78/86. December 1978.

- **Nature of the site.** Without exception, permanent species selected must be adapted the site. Specifically:

1. Plants must be adapted to the **soil.** To termine soil characteristics, tests are necessary establish pH, fertility, texture, depth, perm bility, presence of toxic materials, and wa retention capacity.

It has been noted that in the vast majority cases, topsoil provides the most suitable grow medium for plants because it has the ferti and physical conditions needed for pl growth. In addition, more species are adapted topsoil than to subsurface material.

> Exception: In a few cases, subsoil may provide better plant productivity than topsoil Examples of such subsoils are carbonaceou shales or clay loams, as compared to silty clays. These soils, however, often are in fertile and must be fertilized in order to provide an adequate growth medium. The characteristics of subsoils can be artificially altered to provide the fundamental requirements of plants by fertilizing, liming mulching, adding organic matter, and other treatments.

Even if topsoil provides an excellent grow medium for one type of species—for examp grasses—before mining, it may not be adequ as a growing medium for a postmining use another species—for example, trees—because

rences in rooting depths, nutrient needs,

. Plants must be adapted to local **precipita-** both amounts and seasonal distribution. example, a number of shrub species are par-arly adapted to droughty and saline sites be-e of the structural and physiological adapta- of their roots and foliage.

xception: Some species that would not dinarily be selected because they are fficult to establish may be included if pplemental irrigation is planned and they e adapted to the site. It should be kept in ind, however, that irrigation should be nsidered as short range and used only to tablish the vegetation.

. Plants must be adapted to **local tempera-** s—daily maximums, minimums, and ges.

. Plants must be adapted to **elevation**. This r often affects the length of the growing n. Generally, as elevation increases, the ing season decreases.

. Plants must be adapted to the **slope**. For ple, when shallow rooted plants are not ble for stabilizing a steep hillside, deep-ed species are recommended. Slope angle narily influences soil stability and the unt of incident solar radiation received.

. Plants must be adapted to **aspect**. Plants do well on an eastern exposure may not ve on the southern side of the same hill. ct, or exposure, affects day length, solar tion loads, and growing season length.

Plants must be adapted to local **wind** ve-ies. Wind may cause severe water stress in s, and may affect growth habit, pollination, structure.

Other factors that should be considered potential **fire** risk, and potential invasion of s, and **animals** that may invade the site. pests, such as rodents or grasshoppers, and ficial animals, such as those that will aid in dispersal, should be considered. Some s are so totally dependent on animals for dispersal that the reason a plant is seen on a because of the animals inhabiting it. This example of a beneficial symbiotic relation-between plants and animals.

• **Time and timing considerations.** The species should be planted to coincide with expected moisture, using a fast rooting species where erosion control is crucial, and integrating the planting time with the mining schedule. When possible, plant immediately after the spoils are graded, unless settling is needed for stability.

• **Species compatibility.** In general, mixtures of various adapted grasses and forbs are desirable because they offer a greater range of adaptation. For example, grasses and forbs provide protection against surface runoff and erosion more quickly than do shrubs and trees. Shrubs and trees, however, provide protective cover, resting places, and feed for certain types of wildlife. Other examples of mixtures include warm-season and cool-season grasses, fast growing and slow growing grasses, and forbs and grasses. Especially on sites where the environment can change every few feet, mixtures may include species adapted to each of the different microclimates, moisture levels, and soils. For example, on low fertility sites, it is advisable to include adapted species with low nutritional requirements or those able to fix their own nitrogen. The result of using a well-planned mixture can be a fast establishing, thick, long-term cover that is less vulnerable to pests, disease, drought, and frost.

Exception: The vegetation specialist should realize that mixtures can sometimes cause competition problems. For example, mixing annuals and perennials is risky if the annuals will force out the perennials; therefore, if they are mixed, use only 10 percent or less annuals in the mixture. Two other approaches to solving a potential competition problem are (1) to seed competing plants in alternate rows or strips; (2) to interplant with shrubs and trees following scalping to reduce grass competition.

• **Mechanical limitations.** The selected species should either lend itself to commonly used planting methods, or a planting method should be developed to handle the desired species. (See chapter 5 for more on planting methods.)

• **Seed and seedling availability.** In choosing species, an important factor is their availability. The availability of seeds, container-grown plants, bare-root stock, cuttings, or wildings should be determined. (See chapter 3 for a more complete

discussion of plant material availability.)

- **Maintenance after planting.** While planting a persistent perennial species is of paramount importance, it is also desirable to identify low-maintenance plants because periodic maintenance after planting can be costly. The ideal low-maintenance species would be self-generating, long-lived, disease-resistant, pest-resistant, and require no refertilization or long-term irrigation. Of course, these characteristics are idealistic, and some postmining treatments may be required for many years to maintain a planting. (See chapter 7 for more details on site maintenance.)
- **Cost.** The cost of seeds is usually low compared to the cost of grading and seedbed preparation. Containerized plants, bare-root stock, and seed of native species are more expensive than commercial seed varieties. Rehabilitation personnel should be aware of cost factors when making species recommendations.

Considering all of these criteria, what approach should be taken in selecting the species?

Several approaches are useful, including referring to baseline information regarding the species found on the site, relying on the experience of others in the field, directly observing old disturbed sites on which revegetation h[as] naturally occurred, and referring to informati[on] available from researchers.

Discussion:

Relying on the experiences of others can [be] useful if they have been able to revegetate a si[te] and they have identified some species th[at] appear to be adapted and others that do n[ot]. Direct observation of old disturbed sites whi[ch] have characteristics similar to the site being reh[a]bilitated, however, is probably a more relia[ble] way to identify successful species (fig. 3-5). F[or] example, plant colonization and primary s[uc]cession can be observed on old road cuts, [o]ld road fills, old mines, overgrazed areas, and so [on]. Of course, these sites should display the sa[me] climatic and soil conditions as the area und[er]going rehabilitation. But the reason such [ob]servation is so valuable is that it focuses on th[e] species that have naturally adapted to the [dis]turbance and provides information on natural [se]lection and plant succession.

Generally, the vegetation specialist sho[uld] look for species that are on the low end of [the] successional scale because they will m[ost] actively colonize a disturbance. Some of th[e] primary species have been identified in availa[ble] literature. If the exact species is not known, [...]

Figure 3. Natural plant succession on an abandoned road in the La Sal Mountains, Utah.

Figure 4. A 15-year-old drill site on the Beartooth Plateau, Montana, showing succession.

Figure 5. A 25-year-old exploratory trench cut, showing grass, sedge, and forb succession.

mary successional species are generally the first ones that appear on a disturbed site. Observation of a site that is just beginning to show vegetation will aid in identifying these species.

> **Exception:** Although revegetation personnel may have to begin with primary species in very harsh conditions, such as alpine tundra, in more favorable soil and weather conditions, they do not have to begin at the lowest stages of succession. Fewer species are adapted to the harsh conditions of the alpine and desert areas, and more are adapted to temperate climates.

Once adapted species have been identified on an old disturbance, a seed collection program can begin, and the seeds taken to a controlled environment, such as a greenhouse, for testing. Considerations in testing include the following:

- Although the species may seem to be a commonly known one, it may, in fact, be a hybrid or ecotype that has developed in order to survive on the disturbed site. If this is the case, seeds from other sources of the same species may not be successful on the mined site. Plant breeders can help determine whether or not hybridization exists by analyzing the plants genetically. If hybridization does exist, the vegetation specialist should consider obtaining his parent material sources directly from the old observed site and breeding it in the greenhouse or nursery.
- Some of these species, especially native species, have low vigor, low germination rates, and low productivity; thus, greenhouse or nursery cultivation is recommended to improve these characteristics and make transplanting to the mined site more successful.
- The species must also be tested to determine whether they will adapt to the mine spoils, whether they have tolerance to drought, and whether they will respond to rehabilitation techniques such as fertilization, liming, and mulching.

If these tests are positive, it is quite likely that the species will be very favorable for revegetation.

Two sources of research information on species selection are:

- The National Agricultural Library in Beltsville, Md., and the Science and Educat Administration/Cooperative Educatic Western Regional Coordinating Committee developing a "Computerization of Minel Plant Species in the Semiarid West." When c pleted, this system will allow the vegetat specialist access to data and information on ecological parameters of species of plants t exist on mine spoils or on premined sites. specialist will be able to query the system in ways: (1) by listing several species recognized the site in question, and the system will t give information on other species adapted to area; or (2) by listing precipitation, ann temperatures, and soil conditions, and system will supply a list of plants that sho grow in that area.
- New plants are also being developed scientists. Generally hybrid, these strains con of improved natives, improved introdu species, and a combination of the two. Th genetically new species should be conside when available.

Additional Information:

For more information on "Computerizati of Mineland Plant Species in the Semiarid Wes contact Reclamation Research, Montana St University, Bozeman, Mont. 59717.

For more information on the hybrid breedi program, contact Crops Research Laborato Utah State University (UMC-63), Logan, Ut 84322.

For information on a computer-based tool retrieve information on more than 4,000 plan native and introduced, in the states of Colorac Montana, and Wyoming, contact Plant Inform tion Network (P.I.N.), Dept. of Botany a Plant Pathology, Colorado State University, Fo Collins, Colo. 80523.

For more information on species selectio refer to "Plant Materials for Use on Surfa Mined Lands in Arid and Semi-Arid Regions USDA Handbook. Soil Conservation Servi (SCS-TP 157), Lincoln, Neb. (in press).

For information on selecting adapted speci for high-elevation and alpine tundra sites, se "Rehabilitation of Alpine Tundra D turbances," by R. W. Brown, R. S. Johnsto and D. A. Johnson. J. Soil and Water Conse 33:154-160. 1978.

Chapter 3
PLANT MATERIALS

pter Organizer: Stephen B. Monsen

or Contributors: Stephen B. Monsen, Cyrus McKell, Neil C. Frischknecht, Robert B. guson

Once the plant species have been selected, vegetation specialist must determine what l of plant material should be used, where it be obtained, and how it can be stored. These sions should be made as early as possible, iuse certain seeds are difficult to obtain, and er types of plant materials, such as bare-root ontainer-grown plants, may take months or s of cultivation before they are ready for ting. This chapter will discuss basic conrations for choosing plant materials. Seeds, -root stock, containerized seedlings, cuts, sprigs, rhizomes, plugs, and wildings will discussed; the chapter will also reference ces of information specific to the species sen for revegetation. The selection of one of plant material over another depends on requirements; however, the vegetation ialist should consider using a variety of k. Also note that grasses, as well as forbs and bs, lend themselves to various types of ting stock.

SEEDS

n should seeds be used?

eeds are generally the least expensive plant rials; thus, they should be used when the es germinates easily and sufficient moisture ermination is expected. (Seeds usually need days in a moist, warm soil to germinate and lish.) Other conditions on the site must also vorable to seeding.

Eception: In some cases, for example, when erosion is an extreme problem or under arid conditions, transplants may provide a more effective ground cover than that attained from developing seedlings.

Where can seeds be obtained?

There are a variety of sources for seeds; however, the vegetation specialist must realize that not all seed sources will be satisfactory. The environmental conditions under which a particular plant species has evolved can affect its success on a site having a different environment. Seed types and varieties should be chosen with this fact in mind.

Discussion:

The vegetation specialist should not limit himself to buying seeds from a local dealer if seed dealers in other areas have developed a seed source that more nearly meets his needs. On the other hand, seeds should not be purchased simply because the seed variety is cheaper. The cheaper seed may not be adapted to the soils or climate of the mined site. Contact Forest Service regional reclamation specialists, Soil Conservation Service (SCS) personnel, county agents, State agricultural experiment stations, or other rehabilitation specialists for specific suggestions. Also note the references in "Additional Information" at the end of this chapter.

Common sources of seed include:

- **Plant materials centers.** Soil Conservation Service-sponsored centers have developed improved plant varieties and some centers specialize in growing native and introduced plant materials useful on mined areas. At times, they are producing enough foundation stock to distribute through SCS outlets for demonstration plantings. This, however, is a limited supply source.
- **Commercial seed suppliers.** After the SCS tests and develops plants, seeds are made available to private growers who, in turn, produce

the seed and sell it through major seed companies. These suppliers, however, often do not have all varieties and species useful for mine-land revegetation. It is expected, though, that as demand for such seed types increases over the next few years, supply will increase markedly. When purchasing seed, insist on information on seed sources and germination tests completed by official seed-testing centers.

• **Small, private seed collectors.** There are numerous small local businesses that will collect native seeds. These collectors will work under contract to harvest seeds for specific projects. Lists of these collectors are available from the Soil Conservation Service, State universities, and Forest Service offices.

• **Personal collection effort.** When other seed sources do not have seeds of the species required to revegetate the site, Forest Service or mining rehabilitation personnel can collect their own seed from native stands (fig. 6). It should be noted that this can be done fairly quickly; for example, it is not uncommon for one person to collect 200-300 lb of fourwing saltbush seed in a day.

• **Seed banks.** An extension of the individual collection idea is to develop a seed bank; that is, acquire seeds in season and store them for future use. This can be a useful practice when a mining company knows in advance what its seed needs will be during the next several years, if the seed species can be stored conveniently and properly, or if the species produces sporadic seed crops.

How should seeds be collected?

Methods of seed collection vary greatly, depending on the species. General suggestions follow and references at the end of the chapter will guide the vegetation specialist to sources of information giving more detailed instructions.

Discussion:

The following guidelines are suggested for collecting seeds:

• Collect from an environment as nearly identical to the site being revegetated as possible.

• Collect at the seed's optimum ripening time, and within a time period that will allow the seed to remain viable until planting. For example, some seed can only be stored for 6 months, whereas other seed can be stored for sev years.

• Collect before, not after, storms. Ripe seeds are often disseminated by winds precec storms.

• Test the viability of the seeds by cut and examining a sample number. Genera seeds that are filled are viable.

• Collect from a number of plants of the sa species to obtain genetic variability.

• Correct handling of the seed is import from the time it is collected. Some rules thumb: Cloth bags are better for collecting storing the seed than are plastic bags (fig. Unless recommended otherwise, keep the se cool and dry. The seeds should be cleaned processed promptly after collecting.

• Instruct collectors on proper methods collecting seed.

Additional Information:

For information on seed-collection equ ment, contact the USDA Forest Servi Missoula Equipment Development Center, F Missoula, Mont. 59801.

How should seeds be cleaned and dried?

Generally, it is advisable to let commer seed dealers clean and dry seeds because th can do this job more economically. Major s companies also have the equipment needed clean most seeds.

Discussion:

Seeds should be cleaned soon after collecti to maintain viability. Weeds, insects, and tras material must be separated from the seed. T seeds should then be dried to a proper moistu content.

Drying can be accomplished by spreading t seeds in a thin layer over tarps or plastic she and leaving them exposed to the sun for seve days. The seeds should be stirred each day. collected in the fall, the seeds can be placed in cool, protected building for drying.

What other seed treatments are necessary?

Some seeds require a chemical treatment they will be stored for extended periods of tim seed inoculation may also be required.

Figure 6. Collecting seeds from adapted species.

cussion:

For specific information on treating seeds h fungicides or insecticides, consult seed pub- tions or Soil Conservation Service and State versity scientists.

Most commercial seed growers will inoculate ume seeds with nitrogen-fixing micro- anisms as part of a standard seed treatment. vegetation specialist should check to make this has been done. Native legumes may re- e a different kind of inoculation than those d for introduced species; commercial seed wers should be able to advise the vegetation cialist on this. Cost of inoculation is minimal the treatment is highly beneficial.

t is also known that inoculants other than ones commonly used by commercial essors are important in the successful es- shment of certain species. At this time, ever, these micro-organisms (for example, omycorrhizae), are not available com- ially, and the vegetation specialist will have

Figure 7. Collecting seeds from a large shrub.

to rely on topsoil or soil adjacent to the mined site to supply these organisms.

It is generally better to inoculate seeds just prior to planting them. If the vegetation specialist wishes to store inoculated seed, he should check available literature or consult commercial seed growers on the length of time the inoculated seeds can be successfully stored.

How should seeds be stored?

After cleaning, drying, and other treatment, the seeds should be stored as directed by seed experts or as advised by available literature. This information is quite specific because seeded species react differently to temperature and humidity. The seeds should also be accurately labeled.

Discussion:

While detailed species information is necessary, some general guidelines on seed storage are as follows:

- Keep freshly collected seeds dry and do not expose them to high temperatures.
- While berry seeds are being cleaned they can be held in small (10 lb or less) bags or spread in a thin layer on trays and kept in a refrigerator or walk-in cooler at 34-40° F.
- Properly dried seed may be stored in unheated buildings for several months with little effect on seed viability. Seeds can be kept for longer periods by storing in airtight containers at temperatures between 33° and 38° F. Airtight glass or metal containers are preferable to plastic bags.
- Avoid high humidity and high temperatures; if bagged seed becomes wet by accident, open it immediately and thoroughly air-dry the seed.
- Guard against rodents.
- Facilities such as the National Seed Storage Laboratory at Fort Collins, Colo., can provide information on long-term seed storage; however, in most cases, land managers and mine operators concerned with revegetation will not need to store seed for more than 6-18 months.

Proper labeling is crucial because such records will later help identify which species are best adapted to the site. In general:

- Place labels on the inside and outside of the container. Include: (1) precise species name; (2) seller's or collector's name; (3) date of collection; (4) detailed information on location seed source.
- In the office, a complete file should maintained on all seeds. This file should includ (1) all information on the seed container labe (2) information on germination tests, puri and pure live seed percentage; (3) characterist of the site from which the seed was collecte (4) where and when, precisely, the seed w planted; and (5) what dates the collector recom mends for future seed collections.

CONTAINER-GROWN PLANTING STOCK

When should container-grown planting stock used?

Generally, container-grown planting stoc (fig. 8) is recommended on harsh sites such rocky areas or toxic soils; where establishme may be difficult due to erratic or low precipit tion; where a fast developing ground cover important; or where the higher cost of this stoc is offset by its superior survival rate.

Discussion:

Container-grown planting stock often has greater chance of success than is achieved b direct seeding because the period of time fro seeding through germination, emergence, an early growth is bypassed (fig. 9). Thus, quic plant establishment is obtained.

Container-grown stock has some advantage over bare-root stock. Container-grown stock ca be grown more quickly by suppliers, often th root system of container-grown planting stock i better protected during planting, and survival o certain species has been increased. Also, bare-root planting stock is not available at certai seasons.

The disadvantage of container-grown stock is that some species adapted to mine sites are difficult to cultivate as container stock. Container stock is quite heavy, which presents shipping and handling difficulties, and it may also be more expensive (fig. 10). Container stock is also difficult to maintain from the time it is delivered until field planting is completed. Proper storage areas, watering facilities, and daily care are needed.

Where can container-grown planting stock be obtained?

Limited supplies are available from Forest Service nurseries and State nurseries; private growers also produce such stock.

Discussion:

Of course, some species are more readily available than others. If a desired species is not being cultivated by the nursery, reclamation specialists may be able to provide seed to the nursery. The seed should first be tested for germination.

How should container-grown stock be handled?

In general, the plants must be hardened and kept moist before planting. Specific information for handling individual species should be obtained from specialists having experience with that species.

Discussion:

Hardening is a process done prior to planting to enable the stock to resist cold, heat, or desiccation following planting. If possible, it is desirable for container-grown plants to have been stored outside through one winter season prior to planting; they can usually be kept outside without shelter, if they are packaged in sawdust. If the seedlings are started in the greenhouse during the winter, they may be only 8-10 weeks old when planted in the field. Such young plants should be "hardened-off" for at least 2-3 weeks prior to planting by exposing them to cool temperatures and less watering. If nighttime temperatures do not go below freezing during this time, most plant species will not be killed by frost following field planting. Of course, plants vary in hardiness, and this is one factor to consider in selecting species for revegetation, and in scheduling planting operations. Decreasing the amount of water supplied to seedlings during the "hardening-off" period also helps in toughening the plants.

There is some evidence that very young seedlings are incapable of attaining any freezing tolerance; thus, there may be a minimum age for most plant species, prior to which it is unwise to plant them in the field when chances for the occurrence of subfreezing temperatures are high.

Figure 8. Container-grown seedlings are useful in mineland reclamation.

Figure 9. Containerized seedlings typically exhibit a well-formed root system.

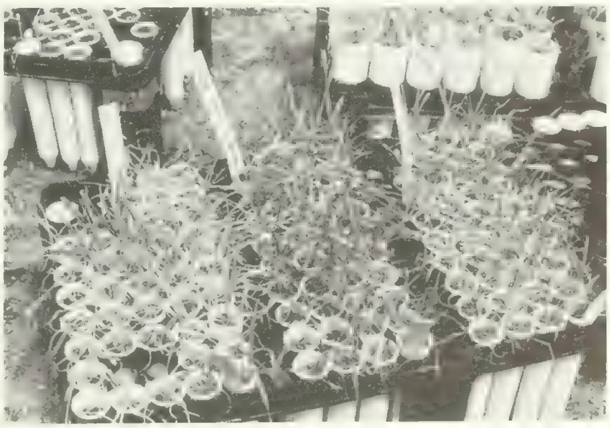

Figure 10. A difficulty in using container-grown stock is its bulkiness.

But presently, there are no standards for size or age of the container-grown plant prior to planting.

BARE-ROOT STOCK

Bare-root stock or nursery-grown stock is usually grown in beds for 1-2 years. After this time, the plants are dug up while dormant, the soil shaken from the roots, and the plants are packaged in moist peat moss in crates. Once taken from the planting beds, bare-root stock can be stored in coolers for as long as a year.

When can bare-root planting stock be used?
Consider using bare-root stock when the species responds to this kind of cultivation; there is sufficient time to propagate the stock; the bare-root plant can be lifted from the nursery during the dormant period; and sufficient soil moisture will be available to root the stock when planted.

Discussion:
Planting bare-root stock provides a means of establishing a fast growing cover on a site; it is less expensive than container-grown stock; and the plants have less need for hardening because they are dormant when packaged. Bare-root plants are easier to ship, plant, store, and handle than is container-grown stock. Most native shrubs and trees can be successfully grown and field planted as nursery stock. On mine spoils, nursery stock has been used very satisfactorily unless the sites are extremely rocky or arid. Only a few woody plants perform better as container stock.

The disadvantages of bare-root stock are that it takes longer to cultivate, and it must be lifted from the nursery and replanted at specific seasons. Also, a few species are not adapted to currently used bare-root cultivation practices.

Where can bare-root stock be obtained?
The same sources that supply container-grown plantings may supply bare-root stock.

Discussion:
Vegetation specialists may be able to provide seeds to nurseries for production of bare-root stock, but often this must be done 1 or 2 years in advance of the projected planting date. Thus seed collection considerations are also involve in this method of obtaining stock.

How is bare-root stock handled?
Although bare-root stock is easier to ship because it is lighter than container stock, plant should be kept in a cold environment.

Discussion:
- The stock must be lifted from nursery bed while dormant and planted while still dorman (fig. 11). The user should schedule planting o the mine site with the lifting of the stock.
- The stock can be shipped in crates, holdin as many as 2,000 plants.
- Plants should be kept in cold storage unt planted, but taken out a day ahead of time t harden or acclimatize the stock.
- En route to the planting site, keep the stoc shaded, moist, and protected from wind blasts At all times, avoid exposing crated or boxe stock to sun or other sources of high tempera tures, and never allow roots to dry out.

What size bare-root stock should be used?
It is advisable to have roots at least 6-8 inche long so deeper soil moisture is available to th transplant. On the other hand, plants with exces sively long roots are difficult to transplant cor rectly on rocky sites.

CUTTINGS, RHIZOMES, SPRIGS

Cuttings are pieces of stems, usually from woody plant, that are either rooted and the planted on the site or directly cut from a plan and replanted on the mine site. Rhizomes ar underground stems of grasses, sedges, or forbs Rhizomes can be rooted and replanted. Sprig are pieces of grasses or sedges that can be roote and replanted.

When should these types of plant stock be used
Cuttings are easily propagated and can be suc cessfully established on harsh sites. They provid a ground cover in a short period of time if th species desired are adapted to this kind of culti vation and enough moisture for plant establish ment is available (fig. 12).

Figure 11. Harvesting bare-root stock.

Figure 12. One-year-old stem cuttings.

Discussion:

Willows are quite adapted to cuttings. Cuttings are also very compatible with direct seeding. Cuttings must be acquired in season and handled according to instructions outlined for various species. Personnel must be trained to properly cut and store the desired materials. Some nurseries cultivate woody cuttings. If an individual plant is identified as adapted to a toxic situation on a mine site, as many as 100 rhizomes or sprigs can be cultivated from this one plant and transplanted to the site. Sprigs and rhizomes are normally taken from herbaceous plants and started in containers or flats.

WILDINGS, PLUGS

Wildings are individual plants transplanted from the wild to another site. Plugs are usually field-grown, native clumps of vegetation dug up and replanted on another site; they may contain several plants.

When should wildings or plugs be used?

They are especially useful when a species adapted to the mined site does not produce a good seed crop. They have the same advantages listed for cuttings, sprigs, and rhizomes.

Discussion:

The desired plant is dug from a wild site and either immediately replanted on the mined sit or taken into a nursery for a year. If nurser grown, segments of the plant can be split fro the parent plants and planted on the mine sit

Additional Information:

For more information, refer to:

"Restoring Big-Game Range in Utah," by A Perry Plummer, Donald R. Christensen, an Stephen B. Monsen, Publication No. 68-3, Uta Division of Fish and Game, Ephraim, Uta 1968.

"Collecting and Handling Seeds of Wil Plants," by N. T. Mirov and Charles J. Kraebe Civilian Conservation Corps, Forestry Publ. 1939.

"Woody-Plant Seed Manual," U.S. Dept. Agric., Misc. Publ. 654. 1948.

"Plant Materials for Use on Surface Mine Lands in Arid and Semi-Arid Regions," USD Handbook. Soil Conservation Service (SCS-T 157), Lincoln, Neb. (in press).

"Selection, Propagation and Field Establis ment of Native Species on Disturbed Ari Lands," Institute for Land Rehabilitation. Uta State Agricultural Experiment Station Bullet 500. 1979.

"Sources of Seeds and Planting Materials i the Western States for Land Rehabilitatio Projects," by Kent Crofts and C. M. McKel Utah Agricultural Station Land Rehabilitatio Series No. 4. 1977.

Chapter 4
SITE PREPARATION

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lajor Contributors: Bland Z. Richardson, Paul . Packer

Prior to planting, adequate site preparation is ssential to provide an environment that will be vithin the physiological tolerances of the plants nd to eliminate erosion problems. Even though ne vegetation specialist may not know the speific tolerance limits of the species selected for lanting, he will know enough about them to dvise on the site conditions necessary for plantng.

Site preparation can include both physical nd chemical treatments. For example, because 1ost mine spoils become compacted, they hould be ripped and then harrowed, or, if the poil is toxic to the vegetation, a chemical treatnent may have to be applied.

Shaping and grading the mine spoils as types f site preparation are discussed in the "User Guide to Soils," USDA For. Serv. Gen. Tech. Rep. INT-68.

PHYSICAL SITE PREPARATION

For the purposes of this discussion, physical ite preparation will be referred to as tillage. Tillage is defined as those mechanical and soil tirring actions carried on for the purpose of esablishing the plant.

Vhy is tillage important?

Proper tillage will provide a suitable environnent for seed germination, root growth, weed ontrol, soil erosion control, and moisture conrol.

Discussion:

Tillage can achieve this goal by:

- Providing soil aeration.
- Incorporating the fertilizer into the soil.
- Incorporating mulches or plant residue into the soil.
- Providing runoff control and a loose surface for good moisture infiltration.
- Reducing compaction, which restricts water movement.
- Providing a looser, cooler, more moist soil for seed germination.
- Providing good seed-to-soil contact.
- Controlling erosion through contour tillage and contour planting.
- Providing a temporary modification of spoils conditions, such as density, aeration, and moisture-retention capacity.

What tillage operations are necessary?

Tillage operations are usually divided into primary and secondary operations and both are necessary. The choice of tillage equipment depends on site and spoil conditions. Contrary to previous belief, however, spoils need to be worked only enough to insure optimum vegetation production; any tillage activity beyond that is of questionable value.

Discussion:

Primary tillage cuts and shatters the spoil and may bury trash by inversion, mix it into the tilled layers, or leave it basically undisturbed. It is a more aggressive and a relatively deeper operation, and thus usually leaves a rougher surface. Shallow and deep ripping (fig. 13), some kinds of disking, chisel plowing, and stubble-mulch tilling are types of primary tillage operations used in surface mine revegetation.

Ripping.

- Deep ripping will shatter spoils packed during placement; shallow ripping will break up impervious spoil layers below the normal tillage depth to improve water infiltration, drainage, and root penetration. Both shallow and deep ripping will allow more vegetation production,

Figure 13. Rippers are very effective in breaking up the compacted spoils typical of mined sites.

Figure 14. The spoils should be dry enough to permit the ripper teeth to shatter the hard layer.

thus increasing the amount of organic matter the spoils.

- If the spoils have been placed using a scrap or similar equipment, the spoils should be dee ripped.
- If spoils placement is accomplished with dragline type operation and graded out with crawler tractor, then the spoils may need to either deep or shallow ripped, depending compaction. Shallow ripping is from 12-1 inches deep.
- On slopes where spoils are dumped dow slope on angles of repose and later are grade out with a front-casting dozer, the dump fro which the graded material was taken should at least shallow ripped and may need to be dee ripped.
- Deep ripping should not be practiced downslope dumps if it has been determined th ripping may later cause surface instability, whic would lead to mass slumping.
- If a dump has been in place for more than year before planting, it should be ripped.
- If a dump was ripped prior to seeding wi an annual cereal species to protect the surfa from erosion until a permanent cover could planted, subsoiling or shallow ripping w probably not be necessary prior to permane planting.
- Always rip dumps on the contour.
- Prior to ripping, the spoils should relatively dry to permit shattering of the ha layer (fig. 14); if the spoils are wet, only a th slot, which may reseal very quickly, will sliced through the spoils.
- Spoils below the ripped layer must ha adequate water-retention capacity or there w be no place for surface water to go, and the r marks will become saturated. If this occurs, t rip marks will not trap the air needed for plar root growth. Vertical mulching can help sol this problem. In vertical mulching, the ripp slit is filled with mulch so that the ripping mar or slits stay moist but not saturated. In additio a subterranean form of erosion called soil pipi may occur.
- The deep spoils that are ripped and broug to the surface must not be so acid or alkaline as to discourage root growth.
- Subsoilers should not penetrate into a de layer of sand if the water table in the sand dro rapidly during dry weather.

• Spacing between standards of the ripper can vary. In general, the best spoil fracturing is obtained by adjusting the distance between the standards to approximately equal the depth of the rippers.

• Tractors and heavy implements should not be driven over the rip marks to prevent resealing of the slit by tire compaction.

Disking.

• Disk tilling is especially useful when the spoils have an established vegetation cover. Disk tilling will produce a mixing action of the spoils rather than inversion.

• Disk harrowing can be used for primary tillage.

Chisel plowing.

• Chisel plowing will penetrate heavy spoils, shatter compacted layers, and break up large clods. When the surface is left broken and open, it will catch and hold rainfall and resist wind erosion. Chisel plowing is probably one of the most useful tillage operations in mine spoils revegetation work.

Stubble mulch tilling.

• Stubble mulch tilling provides a more complete cutting and mixing of trash and deep shattering of the spoils in one operation than either disk harrowing or chisel plowing alone.

Secondary tillage works the spoils to a shallow depth, provides additional pulverization, firms the spoils, closes air pockets, kills weeds, and helps to conserve moisture. Disk harrowing, roller harrowing and packing, and tooth-type harrowing are secondary tillage operations.

Disk harrowing.

• Disk harrowing works extremely well for seedbed preparation, but may not be as effective as the S-tine cultivator harrow on spoils. Spoils that have been disk harrowed are more subject to wind and water erosion.

Roller harrowing and packing.

• This operation is done by roller harrow-packers, also known as cultipackers, cultimulchers, soil pulverizers, or corrugated rollers. It is more effective when used to prepare a seedbed in spoils that have been previously worked while wet. The packer wheels crush the clods, and the harrow teeth bring up more clods, which are subsequently broken by the rear packer wheels. In addition, if the spoils below the surface are a little too wet for good seedbed preparation, repeated trips over the spoils with the roller packer will continue to bring the moist spoils to the surface for better drying. The big advantage of roller harrowing and packing is that it breaks clods, pulverizes and firms the spoils, and closes air pockets. It is effective for preparing a seedbed for range drills.

Tooth-type harrowing.

• This is probably the most versatile of the secondary tillage operations. For example, spring-tooth harrowing can be made to work 3-6 inches deep to loosen spoil crust, and dig, lift, and break clods. If used immediately after ripping, it closes air pockets in the spoils, breaks up clods, and levels the surface to make it ready to plant. Its deeper penetration into crusted spoils and its more aggressive action make spring-tooth harrowing better suited for seedbed preparation than spike-tooth harrowing.

What kinds of equipment are required to carry out tillage operations?

Equipment considerations should be based on the following:

• *Equipment that must be bought versus operations that can be contracted.*

• *Possibility of using farm or mining equipment for mineland revegetation work.*

• *Capability of the machines.*

• *Machine size needed for the site.*

• *Cost of the equipment and its useful life.*

• *Training and manpower required to operate the machinery.*

• *Conditions of the site and treatments required.*

Discussion:

Because of the expense involved in purchasing revegetation equipment compared to the relatively small acreages that are usually involved, contracting out tillage operations may be more economical.

The disadvantage of using mining equipment is that even in cases where it is suitable—such as using a dozer to pull tillage equipment—it may be impossible to count on its availability because its primary use is for mining operations. The disadvantage of some farm machinery is that it is not rugged enough to withstand spoils conditions and the terrain of the mined site.

Various tillage operations have already been discussed, and equipment can be chosen accordingly. But it is also important to note that the

equipment used to pull the tillage machinery is another consideration:

- The small crawler tractor with a wider-than-normal beam between tracks is safe for cross-slope work as steep as 2:1 or on very rough sites. This tractor should be equipped with a hydraulic ripper and a hydraulic three-point lift at the rear.
- On extremely steep, rough slopes, a large crawler-type tractor may have to be used to pull the tillage equipment. The deep ripper is usually pulled by a large crawler tractor.
- Farm-type wheel tractors should be used only if slopes are not too steep. The advantage to farm-type wheel tractors is their greater handling flexibility.

When should tillage operations be done?

Ideally, site preparation should be done as soon as the mined site is shaped and just previous to planting. The general sequence of site preparation is to: (1) rip; (2) disk or harrow; (3) fertilize; (4) harrow in fertilizer; and (5) plant.

Discussion:

In some cases it may be necessary to quickly treat the site and plant a fast establishing vegetative cover on the site to prevent wind and water erosion. If so, a second site preparation will be necessary prior to permanent planting.

Treatments will also vary depending on the site being revegetated. For example, on dumps that have produced weeds prior to permanent planting, the following methods have been recommended.

Where wind erosion is a problem, keep seed heads from maturing by clipping; otherwise, spray herbicides to kill undesirable plants just prior to maturing. Then, plant directly into the spoils with a drill. The stubble-mulch tiller will be very effective when it is desired to mow the weeds and mix a portion of the trash into the spoils, and yet leave enough exposed to control wind erosion.

In areas where wind is not a major problem, use a narrow chisel point to plow as deeply as possible, harrow with a flexible tine cultivator, and plant with a grass seeder packer or drill. The flexible tine cultivator breaks crust, kills weeds, closes air pockets, and leaves the ground ready for planting.

As a specific example, the following site preparation techniques were used at a coal mine sit in Montana (fig. 15-23):

Once the dragline spoils were regraded fc final reclamation in the fall, they were rippe with a number 16 Caterpillar motor grader fc

Figure 15. Ripping spoil.

Figure 16. Laying down topsoil.

Figure 17. Ripping topsoil.

ｅtter moisture and root penetration. A 20-inch yer of topsoil was laid down and then ripped ith a Howard V-chisel to a depth of 14-16 ches to loosen the packed topsoil caused by rapers and to promote better root and moisture penetration. An "Athens" 126 series, heavy duty, 26-inch offset disk was used to further prepare the seedbed. Commercial fertilizer was applied and a "Kongskilde" triple-K-cultivator harrow with "S" curved tines was

igures 15-23. Site preparation sequence. (Dwight Layton, Decker Coal Mine)

Figure 18. Disking.

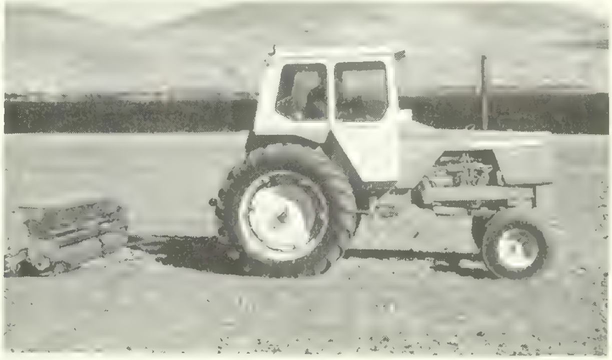


Figure 21. Seeding.

Figure 19. Fertilizing.

Figure 22. Hydromulching.

Figure 20. Harrowing.

Figure 23. Results.

used in the final seedbed preparation to incorporate the fertilizer into the root zone area of the seedbed. The site was planted using a Brillion seeder packer.

OTHER SITE PREPARATION

In addition to tillage, site preparation work may include a program to ameliorate spoil conditions unfavorable to plant growth, such as highly acidic or highly alkaline spoils. Both physical and chemical means can be used to improve these conditions.

When are treatments necessary?

Whether or not the site requires treatments to correct an acid or alkaline condition depends on the spoils' characteristics, as indicated by analysis, and the capability of the desired plant species to adapt to these conditions.

Discussion:

Chemical properties of the spoils are a major consideration for revegetation of disturbed sites because acid and alkaline spoil conditions frequently occur in the West. Acid-mine problems are most often associated with ore production from geologic materials containing sulfide minerals, such as uranium, lead, copper, cobalt, iron, chromium, platinum, and other metals. Alkaline spoils are common to western mining operations. These problem areas are generally found in arid and semi-arid regions where precipitation is insufficient to leach out salts, although they also occur in poorly drained, low lying areas and high water-table areas due to slow leaching.

The parent material from which soil develops controls, to a large extent, the chemical properties of the soil. The productivity of the soil may also be altered by the action of climate and vegetation. Chemical properties modify the soil's physical properties, and the chemical nature of the soil controls the supply and availability of mineral nutrients for the growth of plants and the relative acidity or alkalinity of the medium. The revegetation of such mine sites requires physical and chemical treatments prior to planting as well as selection of adapted plant species. Thus, the role of soil chemistry cannot be overemphasized for successful reclamation of di turbed mine sites.

Soil pH tests can be run to determi whether a soil is acidic or alkaline. Soils va widely in pH. The extreme range that might recorded could be from 3 to 10. Most soils f in the range from 4 to 8.3; most productive so from 5.5 to 8.3, although some sensitive plan may show chlorosis (yellowing of leaves) abo pH 7.5.

• **Acidic soils.** Soils on the acid end of t scale—even the ones at pH 3—produce so kinds of plants. At the extremes of acidity, ho ever, production is low and the number species is somewhat restricted. In fact, t species contained in a plant community a determined as much by acidity as by any oth single soil property.

The influence of acidity on plant growth not generally thought to be associated wi hydrogen ions as such, but to the influence acidity on the solubility and plant availability nutrient elements, such as iron, aluminu manganese, and phosphorus. Poor growth very low pH's may not be due to excessi hydrogen-ion concentrations, but to an exce and toxicity of iron and aluminum, which a very soluble at such acidity levels, and to t lack of phosphorus, which is insoluble und such conditions.

• **Alkaline soils.** Soils in arid areas will tend be basic or alkaline and to remain so because the lack of water needed to leach the basic io after replacement by hydrogen and the presen of a reserve of basic ions (lime). Plant growth alkaline soils is directly related to the presen of hydroxyl ions as well as the solubility a availability of mineral elements.

High salt concentrations reduce the uptake water by plants, retard their growth, and m reduce the uptake of nutrients by plants. Hi concentrations of some salts, such as boron, c even be toxic to plants. The amount of solub salts that may impair plant growth depends the type of salts, the type of soil, and the speci of plant. Arbitrary guidelines, however, ha been established by the U. S. Salinity Lab sta A soil is considered saline if the electrical co ductivity (EC) of a saturated extract is mmho/cm.

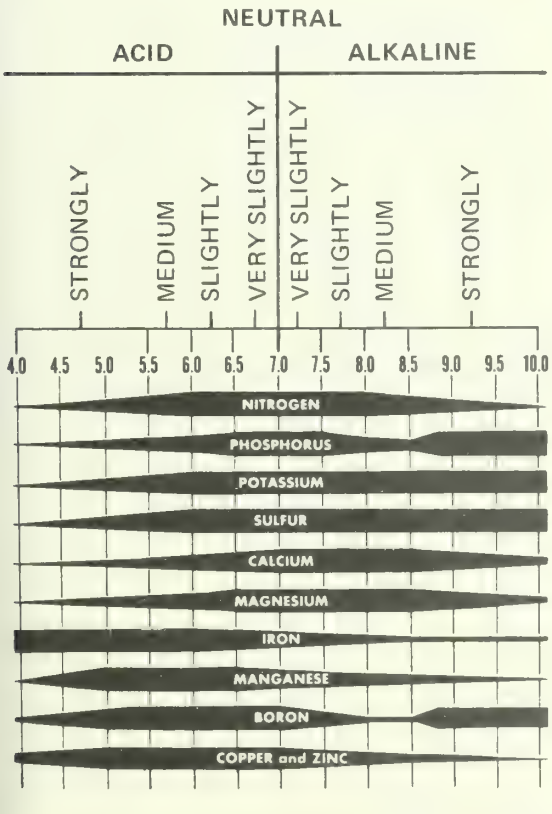
Sodic soils are a specific type of salt-affect soil. They occur when sodium ions are so cc

entrated in the soil that they may adversely ffect plant growth. The percentage of sodium ons a soil can exchange with other salts is called ne exchangeable sodium percentage (ESP), and this figure is 10 percent or higher, the soil may e sodic.

Another lab measurement of a sodic soil is its odium adsorption ratio (SAR). If the SAR is 10 r more, the soil may be sodic.

Sodic soils are highly alkaline. They may be npermeable to water and may crust when dry. ny soil with a pH above 8.5 should be susected of containing sodium. A soil dominated y calcium seldom will exceed pH 8.3. A soil aving a pH of 10 will generally not grow plants, vill probably be dispersed, and will be xtremely difficult to manage.

Based on the determination that a soil is ither acidic or alkaline, a program can be underken to correct the soil condition if it is known nat the type of plant species to be grown on the te will not tolerate the soil. Certain plant



igure 24. How pH affects nutrient availability. Texas Agricultural Extension Service)

species, however, will adapt to acidic or alkaline conditions. For example, some pine trees prefer a slightly acidic soil with a pH of 5.5 or 6; many grasses prefer slightly alkaline soils. This is because soil pH affects the ability of the plants to take in nutrients (fig. 24), and various species need different amounts of these nutrients.

Consult plant physiologists, county agents, or the Soil Conservation Service to determine if the plant species desired will be adversely affected by the soil conditions indicated by soils analysis. If this is the case, apply appropriate treatments.

How is an acidic soil treated?

In addition to certain physical treatments, adding lime to the soil is the most common chemical treatment for acidic soils (fig. 25).

Discussion:

Physical treatments to correct acidic conditions can include the addition of organic matter to the spoil. Topsoiling is another treatment that adds organic matter as well as burying spoils deeper, thereby further reducing oxidation.

Whenever acid-producing spoils are ripped or harrowed, lime must be applied to the depth of the soil disturbance. Such application will maintain a neutral soil as oxidation takes place. Be-

Figure 25. Preparing to lime acidic spoils.

cause acid soils and acid drainage water both result from the oxidation of minerals (such as sulfides) located on or near the soil surface, the stability of surface materials is also a major influence on acid production. Thus, control of erosion merits special consideration in reducing high concentrations of acids in the soil. Establishing a quick growing vegetation on the site is probably the best way to control erosion and slow acid production.

Lime can be added to the acidic soil in these forms:

- Ground limestone, or calcium carbonate.
- Burnt lime, or calcium oxide.
- Hydrated lime, or calcium hydroxide.
- Lime residue from sugar-beet processing.

To determine what type of lime to use, several considerations are involved. Ground limestone is very insoluble in water but quite soluble in an acid. It should be mixed at least 10 inches deep into the spoils. Therefore, if a long-range effect is desired, use agricultural limestone. Calcium oxide and calcium hydroxide are forms of lime that are very soluble in water. These forms can be used for an immediate effect but would not be long lasting. For example, ground limestone (calcium carbonate) was used on the Blackbird, a copper-cobalt mine in Idaho that receives 25-40 inches of precipitation annually. Particle size ranged from 200 mesh to 3/8 inch. This variation will permit longer effectiveness of the calcium carbonate in treating acid spoils. The calcium carbonate used on the Blackbird is expected to remain active for at least 10 years.

In addition to correcting a low pH, lime will:

- Improve the physical condition of soil.
- Add calcium to the soil.
- Accelerate decomposition of organic matter, providing for the release of nitrogen.
- Increase fertilizer efficiency.
- Increase nutrient availability.
- Decrease toxicity of aluminum and ferric ions.

How is an alkaline soil treated?

Physical treatments include leaching exces soluble salts through irrigation, adding organi matter to the soil, selecting salt-tolerant plan species, and seeding when the soil is well supplied with water. Chemical treatments fo sodic soils involve the addition of either a solu ble calcium salt or an acid or acid-former.

Discussion:

Chemical treatments are generally reserve for sodic soils. The two most often used chemi cal types are: soluble calcium salts—calcium chloride and calcium sulfate (gypsum); and acid or acid-formers—sulfur, sulfuric acid, iro sulfate, aluminum sulfate, and lime sulfur.

Soluble calcium salts may be used universall on sodic soils. Calcium chloride is more solubl than gypsum and has a more immediate effect Gypsum is less soluble, less expensive, and has more long-range effect. Acids added to soils con taining no alkaline earth carbonates may mak the soils excessively acidic. Sulfur and sulfuri acid are useful to treat limey soils. Rely on soil analysis for specific types and amounts o amendments to use.

Additional Information:

For more information on treating chemica and physical problems in mine spoils, refer t the "User Guide to Soils," USDA For. Serv Gen. Tech. Rep. INT-68.

Also See: "Handbook on Soils," USDA For Serv., FSH 2509.15. Amended July 1969.

Chapter 5
PLANTING METHODS

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Regardless of the type of planting method sed, the purpose is the same: to place the seed r plant in contact with the soil, cover it pro-erly, and firm the soil to keep the seed or plant n place and to eliminate air spaces. The vegeta-ion specialist, however, should realize that al-hough many agricultural principles apply to nineland planting, the mine site has a subsurface uite different from rangeland or cropland. Thus, recommendations on times to plant and lanting methods may differ from methods com-nonly accepted by range managers or farmers in he area. Even the esthetics of mineland planting liffer from farming. Cluster planting or land-cape planting that follows the terrain of the and is preferable to planting in neatly spaced ows across the acreage.

This chapter will give some general guidelines on planting times, seeding methods and equip-nent, planting other types of plant material, and nixed plantings.

TIME TO PLANT

Planting times will, of course, depend on nany factors: the climate; the type of planting tock and soil; moisture needs of the species; rost heaving problems; anticipated erosion roblems; sufficient dryness to allow equipment onto the site; and the time of year mining activi-ies conclude. But, in general, planting times hould coincide with the longest precipitation eason or favorable period of time that may be ivailable for seedling or transplant establishment.

How can the best planting time be determined?

An examination of baseline data dealing with the climatic regime of the area and several years of temperature/precipitation relationships will aid in determining favorable planting periods. This information can be related to the amount of time needed for plant establishment.

Discussion:

Baseline data will help indicate if a region is subject to false plant growth starts; for example, the region may have early precipitation that wets the soil and may initiate seed germination, followed by a long dry period. Of course, this information will be very general and weather conditions may vary in the planting year under study, thus causing a change in planting times. Tables 3 through 6 discuss some of the advantages of fall, winter, spring and summer plantings in four climatic regions; however, as always, the vegetation specialist must realize that these are only general guidelines and weather conditions of a particular year may alter their value.

How should the mine site be treated when the spoils are ready for planting at a time other than the optimum planting time?

If the area is subject to heavy wind and water erosion, the topsoil should be laid on the spoils during a period of low wind and rainfall activity, and it should be seeded with a fast establishing grass that may or may not be the permanent species desired. If erosion is not a problem, the topsoil can be laid down and the planting crews can wait for an optimum planting time. If it is impossible to lay down the topsoil and keep it sufficiently protected, it should be stockpiled until a favorable planting time arrives.

Table 3. — *Time to plant, Northern Great Plains timing matrix*

	Spring		Summer		Fall[1]		Winter	
Activity	Advantages	Disadvantages	Advantages	Disadvantages	Advantages	Disadvantages	Advantages	Disadvantages
Direct seeding[2]	Most optimum conditions probable between early March and late April. Seedlings must emerge before start of spring rains. Topsoil receives best protection at this time	Access can be a problem		Optimum planting conditions have passed—would require irrigation. Postpone seeding to fall	Provides best access and weather for planting. Stratification important to native and shrub seed. More time available to plant	Topsoil and seedbed protection a problem		Seeding on snow is possible but wind may destroy seedling. Seedbed preparation and access are difficult
Bare root	Essential to plant early between frosts and snowstorms so that roots will develop before buds break dormancy. Plant immediately prior to maximum soil moisture season	Timing is very critical		Storage a problem. Seed dormancy broken. Soil too dry. Plants will burn. Lack of necessary moisture	Plants can be planted when dormant and become better acclimated to site if planted after frost	Some species not adapted to fall planting	Not recommended	
Containerized	Most optimum conditions exist very early in spring between frosts and snowstorms	Disadvantage is that stock is usually not ready or available. Access sometimes a problem	Not recommended		Same as above	Same as above	Not recommended	

PROVIDED BY R.C. HODDER

Climate Summary: Considered a continental climate, with warm summers and cold winters. Temperatures can range from -40° F to +105° F. Average precipitation about 12 inches, but can vary from 4 to 18 inches annually in various localities. Precipitation dependent on snowmelt and spring rains that fall between April and mid-June. High wind and high evaporation rates common.

[1] Fall season implies terminal season of the year and that seeds and plants will remain dormant until spring.

[2] Direct seeding involves the use of machinery to place seed in a shallow furrow and cover it with soil. Firming of soil around seeds and placement of fertilizer near to seeds may be accomplished on sites where required. If seeds are broadcast rather than drill seeded, some action to cover them with soil is essential unless it is on freshly graded spoils where natural sloughing will cover the seed.

Table 4. — *Time to plant, alpine timing matrix*

	Spring	Summer		Fall[1]		Winter
tivity		Advantages	Disadvantages	Advantages	Disadvantages	
ect ding[2] asses, sedges, bs)	Sites not accessible	None	Optimum site conditions have already passed. Site may remain too dry. Seed not yet ready to be collected	Provides for dormancy requirements. Site conditions are usually optimum in fall (e.g., not too wet). Seed will be in place next spring when conditions are optimum	Seed collection of natives may coincide with optimum planting times. Seeds may have to be collected 1 year ahead, or purchased commercially from nurseries. If seeding is too early, frost damage to germinating seedlings may occur	Sites not accessible
'e-root ck	Not recommended in this life-zone					
ntainerized elings or na- e plugs (grass, ges, forbs, and ne shrubs and es)	Sites not accessible	None	Actively growing plants may not be hardened-off to low temperatures. Conditions not favorable	Plant only after dormancy is induced. Site conditions are usually most favorable	Frost thrusting may lift plants if not firmly packed. High risk of severe storm activity	Sites not accessible

PROVIDED BY R.W. BROWN

imate Summary: Short growing season of 45 to 80 days; low summer temperatures averaging about 43°F, high wind speeds, high ar radiation loads, and no frost-free periods (needle ice thrusting can occur at any time). Seasons of summer and fall are compressed about 2 months, and winter and spring together are about 10 months.

[1] Fall season implies terminal season of the year and that seeds and plants will remain dormant until spring.

[2] Direct seeding involves the use of machinery to place seed in a shallow furrow and cover it with soil. Firming of soil around seeds l placement of fertilizer near to seeds may be accomplished on sites where required. If seeds are broadcast rather than drill seeded, ne action to cover them with soil is essential unless it is on freshly graded spoils where natural sloughing will cover the seed.

iscussion:

Whenever erosion may be a problem, the topoil must be quickly protected by some kind of egetation. So, the vegetation specialist may ave to seed with a temporary species at a time f year less than ideal and replant with the deired species at a later date. Economically, the opsoil resource is more valuable than the seed, nd it should be given priority. In addition, it is enerally better to replace the topsoil as quickly s possible after the mining operation has left he site to preserve the micro-organisms present ı the topsoil rather than trying to stockpile it.

When wind or water erosion will not be a roblem and the chances of plant establishment re poor, the topsoil can be spread on the site everal months prior to planting.

low can the problem of trying to plant at a ess-than-optimum time be avoided?

By coordinating the ideal planting time with the overall rehabilitation program, the vegetation specialist may be able to avoid the problem of having to determine whether or not to plant at a less-than-ideal time of year.

Discussion:

Once the ideal time for revegetating has been determined, other aspects of the rehabilitation program should be scheduled for that target date. For example, planting materials should be ordered sufficiently in advance of the planting date. In addition, the mine operator should be encouraged to schedule mining operations to conclude in time to meet optimum planting seasons.

PLANTING SEEDS

Seeds are planted by either drilling or broadcasting. Drilling is a method of planting by which the seeds are dropped from a seeding machine into holes or furrows and then covered with earth. Broadcasting scatters the seed on the

Table 5. — *Time to plant, Great Basin Range and Foothills, and Colorado Plateau timing matrix*

	Spring		Summer		Fall[1]		Winter
Activity	Advantages	Disadvantages	Advantages	Disadvantages	Advantages	Disadvantages	
Direct seeding[2]	Favorable temperature/ precipitation for seedling establishment	Late winter may reduce time available for seeding. Late frost or a short spring may reduce seedling establishment or growth	Not recommended		Seeds may receive needed cold treatment and germinate in late winter	Early winter may prevent completion of seeding operations	Not recommend
Bare-root planting	Plant can establish if planted before summer drought	A short spring season may reduce survival	Not recommended		Plant mid-fall. Avoid late fall planting	Frost heaving in heavy soils. Open winters	Not recommend
Transplanting container-grown plants	Best results for establishment are in spring. Hazards of seed germination and establishment are bypassed	Weather may be a problem in scheduling field work	Possible if can be planted in moist soil. Long period of planting is possible	High temperatures and drought can be detrimental	Best results for establishment. Plant early to mid-fall	Frost heaving. Open winters	Not recommend

PROVIDED BY CY McKE

Climate Summary: An area of isolated mountain ranges and extensive level valleys where a highly variable frost-free growing sea may be from 120-180 days in the valleys and less than 110 days in the foothills. Spring and fall temperatures are generally moder (50° F), but high summer temperatures may reach in excess of about 98° F. Warm season precipitation from erratic thunder-shower less than half of the total precipitation of about 6-16 inches annually.

[1] Fall season implies terminal season of the year and that seeds and plants will remain dormant until spring.

[2] Direct seeding involves the use of machinery to place seed in a shallow furrow and cover it with soil. Firming of soil around se and placement of fertilizer near to seeds may be accomplished on sites where required. If seeds are broadcast rather than drill seed some action to cover them with soil is essential unless it is on freshly graded spoils where natural sloughing will cover the seed.

ground's surface, and the seeds may or may not be covered with earth in a subsequent operation. Broadcasting also includes hydroseeding and aerial seeding. Both drilling and broadcasting can be done with machines or by hand.

Which method is best for seed planting?

Drilling is the superior method of seeding where site conditions permit; however, in some cases, the site may only be accessible to a type of broadcast seeding.

Discussion:

Drilling is considered superior because the seed will be covered to a proper depth, seed distribution is uniform, rate of seeding is controlled, and soil compaction can be accomplished with packer wheels attached to the drill (fig. 26). Broadcasting is considered less efficie because the seeds often perch on top of the sc where germination and establishment are diff cult, if not impossible. Rodents and birds ma pick up broadcast seed and eat it or carry away to a seed cache. Seed that is broadca should always receive some mechanical trea ment to give it suitable coverage unless the be is loose so that natural sloughing of soil wi cover the seed. Table 7 compares these tw methods of seeding.

It is recommended that planting be done o the contour to trap available moisture and pr vent erosion.

Exception: On slopes too steep for planting equipment, and where ripping has been done on the contour, planting may have to be done up and down the slope, recogniz-

Table 6. — *Time to plant, semiarid timing matrix*

	Spring		Summer		Fall[1]		Winter	
ctivity	Advantages	Disadvantages	Advantages	Disadvantages	Advantages	Disadvantages	Advantages	Disadvantages
rect eding[2] rasses)	Cool season species only	Winter moisture variable	Warm season species. More reliable precipitation. Plant prior to July-Aug rains	None	None	Frost heaving. Limited fall growth	None	Unsuitable for germination and growth
ire root nrubs)	Not recommended		Plant after initiation of summer rains. Soil moisture must be near saturation	Timing critical. Variable precipitation	If summer rains are late, early fall plantings are possible	Frost heaving	Not recommended	
ontainerized edlings nrubs)	Not recommended		Soil moisture must be near saturation	Variable precipitation	If summer rains are late, early fall plantings are possible	Frost heaving	Not recommended	

PROVIDED BY EARL ALDON

imate Summary: Semiarid mesas and valleys of northwestern New Mexico and northeastern Arizona are characterized by low, ghly variable rainfall and high summer temperatures. Highest rainfall months are July and August with occasional late summer storms tending into September. Driest months are May and June. Rainfall varies with elevation, but in lower areas averages 7-10 inches nually. Snowfall light most years and seldom remains on ground. Growing season ranges from 140-180 days.

[1] Fall season implies terminal season of the year and that seeds and plants will remain dormant until spring.

[2] Direct seeding involves the use of machinery to place seed in a shallow furrow and cover it with soil. Firming of soil around seeds id placement of fertilizer near to seeds may be accomplished on sites where required. If seeds are broadcast rather than drill seeded, me action to cover them with soil is essential unless it is on freshly graded spoils where natural sloughing will cover the seed.

ing that some erosion may occur because of wheel tracks.

Vhat steps must be taken when planting seeds?

After the time of year to plant has been determined, the seedbed must be prepared, the equipment selected for either drilling or broadcasting, the seed planted and covered, and necessary cultural treatments, such as mulches or fertilizers, added to the site.

Discussion:

If the site is too steep or rocky for conventional equipment to till it (see chapter 4), the surface should be roughed in some other way to oosen the soil crust and allow the seed to come n contact with the soil. Chaining is one way to achieve this rudimentary type of seedbed preparation.

Exception: Broadcast seeding is sometimes satisfactory without seedbed preparation if the mine spoils are seeded immediately after they are graded and before the surface becomes crusted.

Numerous types of drills and broadcasters are on the market; the following are only a few that have proved successful in mineland reclamation. Selection of specific equipment will depend on their availability, capability, characteristics of the site, and treatment required.

Drilling:

• **Seeder-cultipacker** (fig. 27). Also called the grass-seed planter or seeder-packer drill, the seeder-cultipacker has a fluted feed to meter seed from the hopper. The seedbed is prepared in previously tilled soils by the front rollers, which break up clods and close air spaces in the spoils. Seeds are dropped in furrows formed by

Table 7. – *Seeding methods advantages/disadvantages*

Characteristics	Drilling		Broadcasting			
	Machine	Hand	Hydroseeding	Other Machines	Hand	Aerial
Topography	Steep slopes and access are problems; if slopes are greater than 3:1, broadcasting recommended	Less limited	Can handle steep terrain, depending on distance	May be limited by steep terrain	Less limited	Unlimited
Obstructions	Limits use	Unlimited	Unlimited	Somewhat limited	Unlimited	Unlimited
Compacted Soil	Possible	Possible	Not acceptable	Not acceptable	Not acceptable	Not acceptable; soil must be rough enough fo wind and rain tc cover seeds
Seeding Depth	Variable and controlled	Variable; somewhat less controlled	Lays on top of the soil	No direct control; depends on soil	No direct control	No direct contr
Seed Size	Variable if drills can be adjusted	Variable if hand-held machines can be adjusted	Small seed	Variable	Variable	Variable
Season	Limited by moisture	Limited by moisture	Limited by low expected mois-	Less limited	Less limited	Less limited
Precipitation	Slightly critical	Slightly critical	Very critical; more success when annual precip. exceeds 12-14 inches	Very critical	Very critical	Very critical
Soil Texture	Not critical	Not critical	Critical	Critical	Critical	Critical
Seed Distribution	Uniform	Uniform if person is well trained; seeds can be precisely placed	Less uniform	Less uniform	Not uniform but can be specific to one area	Not uniform
Mulching	Separate treatment	Separate	Same treatment possible but not advised	Separate	Separate	Separate
Cost	Medium	Depends on how many people needed	High	Low	Depends on number of crews needed	Low if surface area to be covered is extensive
Equipment	Special in some cases	Some hand-held equipment available	Scarce	Available	Some hand-held equipment available	Various types available; can be contracted out

Table 7. *(Continued)*

Characteristics	Drilling		Broadcasting			
	Machine	Hand	Hydroseeding	Other Machines	Hand	Aerial
Seed Rate	Less than broadcasting; drastically disturbed sites such as spoils require much heavier seeding rates than do sites where topsoil and some plant cover are intact. Examples: 10-15 lb/acre drilled on north-facing gentle slopes with small grass seed; 25-30 lb/acre if species seed is large; 40-45 lb/acre if conditions are severe, such as south-facing steep slopes	Same as machine drilling	More; as much as double the drilling rate	More	More	More; 1/3 more than drilling
Trash in Seeds	Must be cleaned from seeds	Must be cleaned from seeds	Cleaning not critical	Cleaning not critical	Cleaning not critical	Cleaning not critical
Time required/acre to seed	Middle range	High range	Low range	Low range	High range	Lowest

the front rollers. Rear rollers split the rows, plant the seeds, and compact soil around them to insure optimum germination. This seeder, designed for planting grasses and legumes, is capable of planting in rough terrain as long as it can be operated safely. It can also be used for covering seed that has been broadcast.

• **Rangeland drill (fig. 28).** This single-disk, deep-furrow drill with a high clearance has the advantage of being able to plant to greater depths in low precipitation areas. It is useful on clay loam soils that have been previously tilled. Its weakness is that it cannot readily handle trashy seed. This drill can accommodate rough terrain.

• **Steep-slope seeder (fig. 29).** This planter can be considered a combination drill and broadcaster. It is attached to the end of a hydraulic crane and extendable boom, and thus can plant seeds on very steep slopes, such as road fills and cuts. The seeder's teeth rough up the surface, the seed is broadcast, and drags cover the seed.

• **Nesbitt single or double disk drill with depth bands.** This drill is useful on gentle slopes in sandy or sandy loam soils.

• **Noble drill.** This drill is adapted to compacted, rocky, or gravelly soils.

Broadcasting:

• **Centrifugal-type broadcaster.** Also called end gate seeder, this broadcaster provides an economical method of seeding most varieties of seeds as well as applying granular and pelleted fertilizers. Centrifugal-type broadcasters generally have an effective spreading width of about 20-40 ft, depending on the physical characteristics of the seed. Hoppers are available that hold from 75-2,000 lb of seed or fertilizer.

• **Field distributor.** Also called full-width feed broadcaster, this machine consists of a seed box with metering devices along its full width. It does not have furrow openers or seed covers. Separate field operations are required to prepare the seedbed and cover the seed.

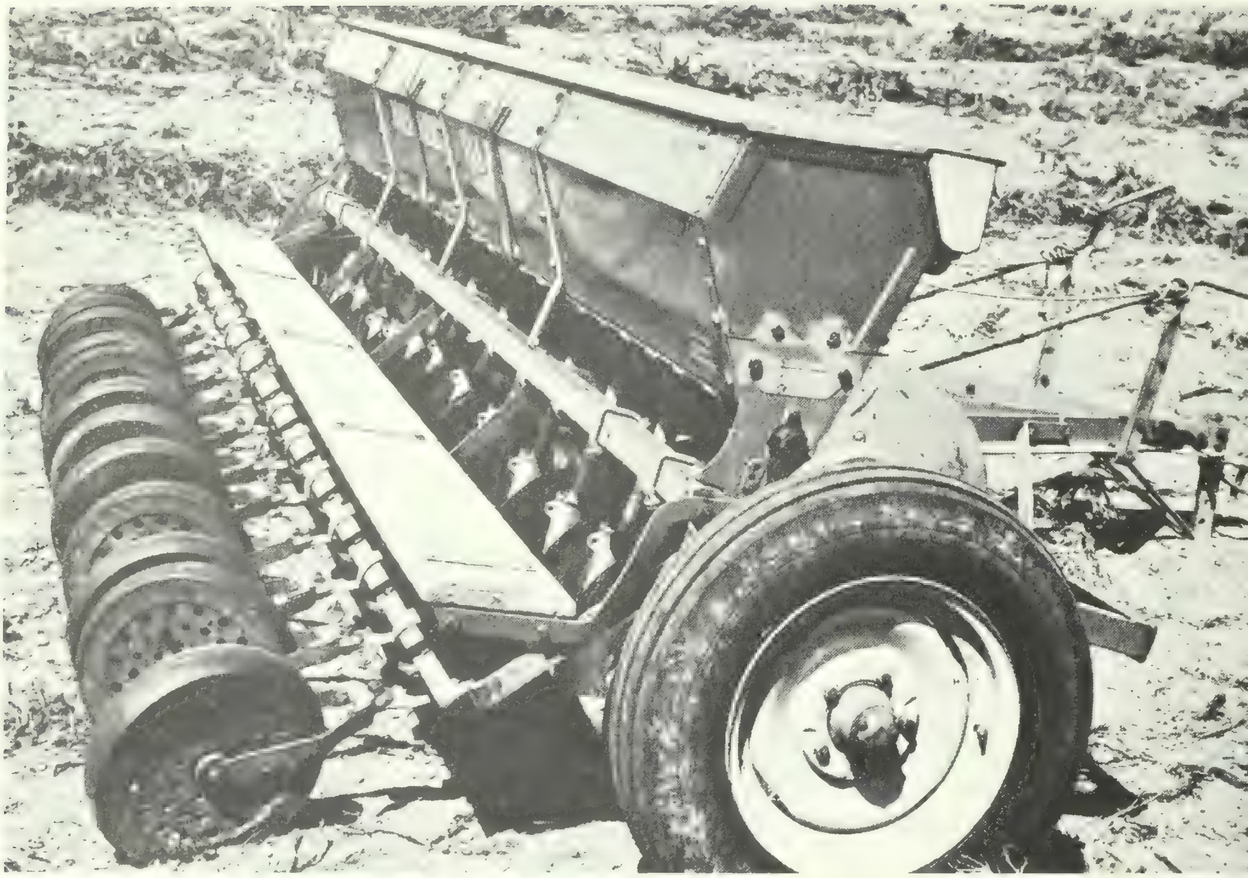

Figure 26. Packer wheels compact soil after drilling. (Utah Div. of Wildlife Resources)

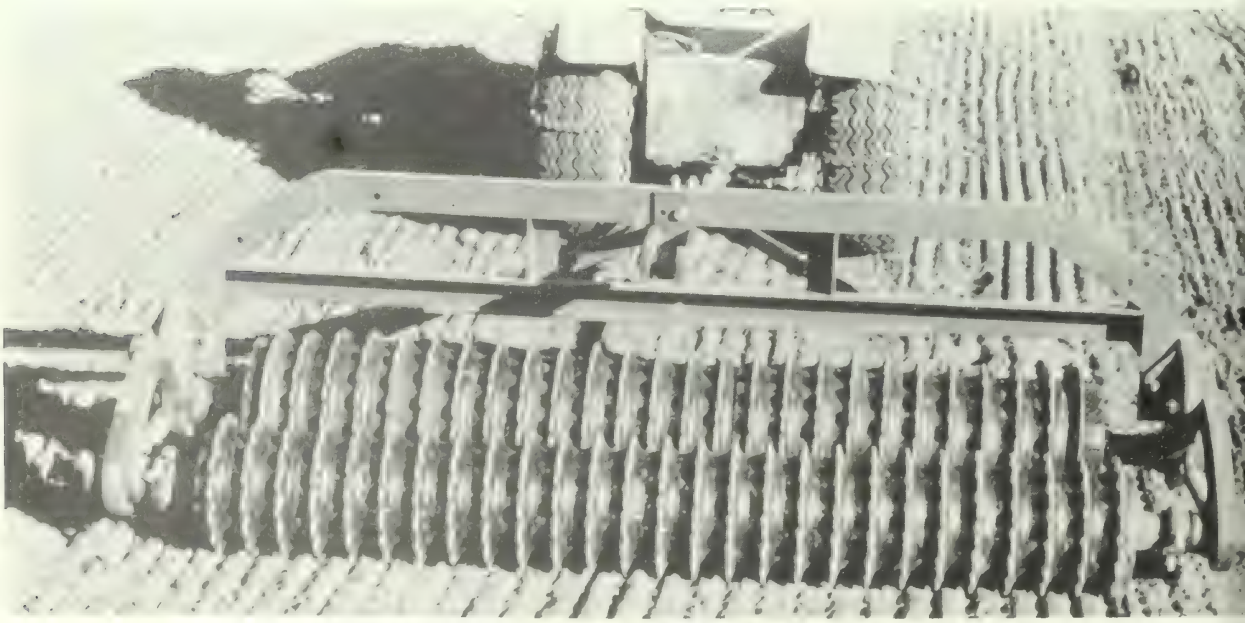

Figure 27. The seeder-cultipacker has been quite successful in mineland revegetation work.

• **Fan or airblast seeder**. This seeder can be pulled by a machine or is also available as a small, portable, hand-held version called the cyclone seeder.

• **Hydroseeder (fig. 30)**. This machine applies seed by means of a high-pressure stream of water. The seed must be covered with soil or mulch in a separate operation to insure germination and establishment. This can be done by harrowing, disking, or using a small sheepsfoot roller. The same machine can apply mulch. If seed is applied with a mulch, the seed need not be covered with soil because the water/mulch mixture will act as a soil covering. Some research indicates, however, that this approach is not always successful because the mulch may prevent the seed from coming in contact with the soil.

Aerial seeders:

Aerial seeding, which is simply another way of broadcasting, is advantageous where the terrain is too rough to use land-going equipment. Often, these sites can be roughed up, for example by use of a chain (fig. 31), but not tilled enough to allow a drill to go over the site. Aerial seeding also provides maneuverability among sites, and it can be used in situations where the vegetation specialist wants to introduce some additional species into the area without disturbing the vegetation currently growing on the site.

Both fixed-wing and helicopter craft can be used for aerial seeding (fig. 32 and 33). The aircraft should be equipped with a positive, power-driven, seed-metering device. An adjustable opening, which allows the seed to drop out of the hopper by gravity, is not acceptable when a mixture of various seed sizes and weights is used.

Aerial seeding operations are normally contracted for. If the contract is based on an hourly

Figure 29. The steep-slope seeder is considered a combination drill and broadcaster.

Figure 30. Hydroseeding is a type of broadcasting.

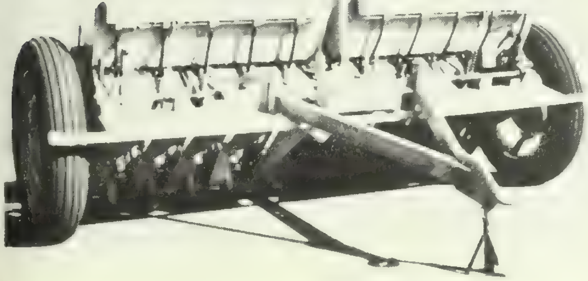

Figure 28. Rangeland drill, front view.

rate, it is recommended that the seed and all plans be ready before the aircraft arrives.

A crew should be on hand to guide the pilot in making overlapping passes. The operation should be delayed if the wind is too strong to get even seed distribution.

PLANTING OTHER STOCK

How is container grown stock planted?

In most cases, these seedlings should be planted by hand. Various hand-held planting tools have been developed, and limited success has been achieved using the equipment built to plant bare-root stock. Because sprigs and rhizomes are usually cultivated as tubelings, they should be planted in the same manner as other container-grown stock.

Discussion:

Machine planting will be efficient only if there is a large number of plants that can be placed in long, continuous rows, the terrain is suitable, and the machinery will not destroy the site preparation design.

Hand methods are mandatory when site preparation includes surface shaping treatments that would be damaged by subsequent machine operations. For instance, contour furrowing, gouging, and land imprinting are examples of site preparation that can be damaged by machines once these operations have been done. In addition, use hand methods when the terrain is extremely steep, or the spoil material is so rocky that proper machine planting would be difficult. When plants are to be set in groups or clumps, or when complex mixed plantings of several species are made, hand planting is necessary.

The following procedure is recommended for planting container-grown stock: Handle the stock prior to planting as described in chapter 3. When ready to plant, make a hole with a mattock, an auger, or a dibble punch (fig. 34). Judge the depth of the hole needed by looking at the size of the root system and depth of the plant container. Remove the plant from the container. Plant the container-grown seedling carefully, keeping the root plug intact, and firm the soil around the plant to eliminate air space.

How is bare-root stock planted?

Bare-root stock must be properly placed in

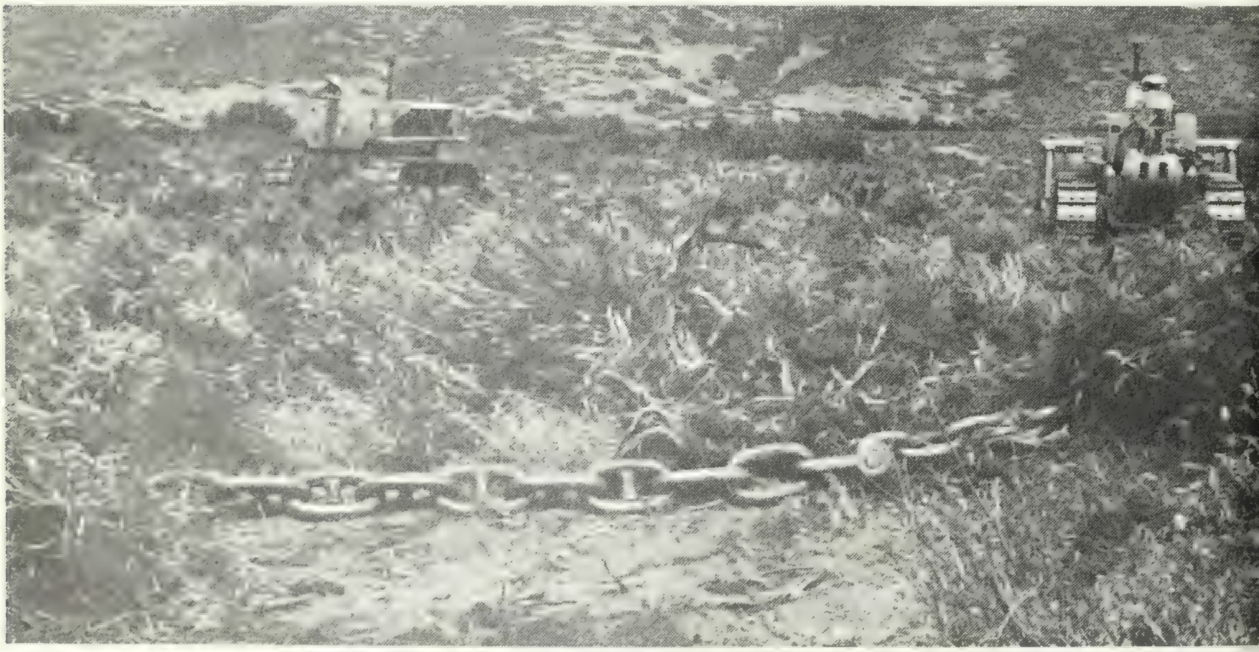

Figure 31. Anchor chaining is an adequate method for covering seed when tillage is extremely difficult. (Utah Div. of Wildlife Resources)

such a way to insure that the roots are well distributed, and firmly in contact with the soil to eliminate air pockets.

Discussion:

Prior to planting, the bare-root stock must be adequately cared for as described in chapter 3. Generally, spacing of the bare-root stock ought not to be less than 1-1/2 times the diameter of the mature plant. Do not expect greater plant densities on revegetated sites than occur on undisturbed sites.

When planting where risk of failure is high, current research recommends cross-wind furrowing and mulching to conserve moisture and trickle irrigation systems to provide supplemental moisture for one or two growing seasons. (For more on cultural treatments, such as irrigation, see chapter 6.)

How are cuttings planted?

Cuttings can be planted either rooted or unrooted when a favorable period of soil moisture exists.

Discussion:

When the cuttings are not rooted, they should be put in the ground only when a favorable period of soil moisture and temperature is expected for at least 30-45 days. Plant cuttings before they have broken dormancy and with a

Figure 32. Fixed-wing aircraft can seed rough areas if rainfall is adequate for seed germination. (Utah Div. of Wildlife Resources)

minimum amount of top exposed — less than 2 inches of a 1-ft-long cutting.

When the cuttings have been previously rooted in a greenhouse, plant them like container-grown stock.

Trees with trunk diameters of 1-1/2 inches or less can be planted like cuttings. Pack the soil closely around the cuttings so that there is good contact with the soil and no air space. Tree cuttings are recommended whenever the species adapts to cutting (willows and poplars, for example) and when there is enough moisture for them to become established. Cuttings as long as 4 ft can be planted. Cuttings such as these have been successfully established along streambanks to aid in water erosion control. Even if they are washed away by flooding, they will often continue to sprout on the bank. Tree cuttings can also be planted earlier in the year than other kinds of stock.

How are wildings and plugs planted?

These kinds of plant stock can either be directly transplanted from their natural habitat to the mine site, or, if they are nurtured in the greenhouse, they can be planted the same as container-grown stock.

Discussion:

When plugs are dug from native vegetation, they can be planted on the site using a shovel. Pack the soil tightly around the roots to eliminate air space. Nursery grown plugs and wildings can be planted in a similar fashion; however, a planting bar or dibble is recommended over a shovel.

How can trees be planted?

Planting seedlings has been covered earlier in

Figure 33. Helicopters are ideal for seeding irregular areas.

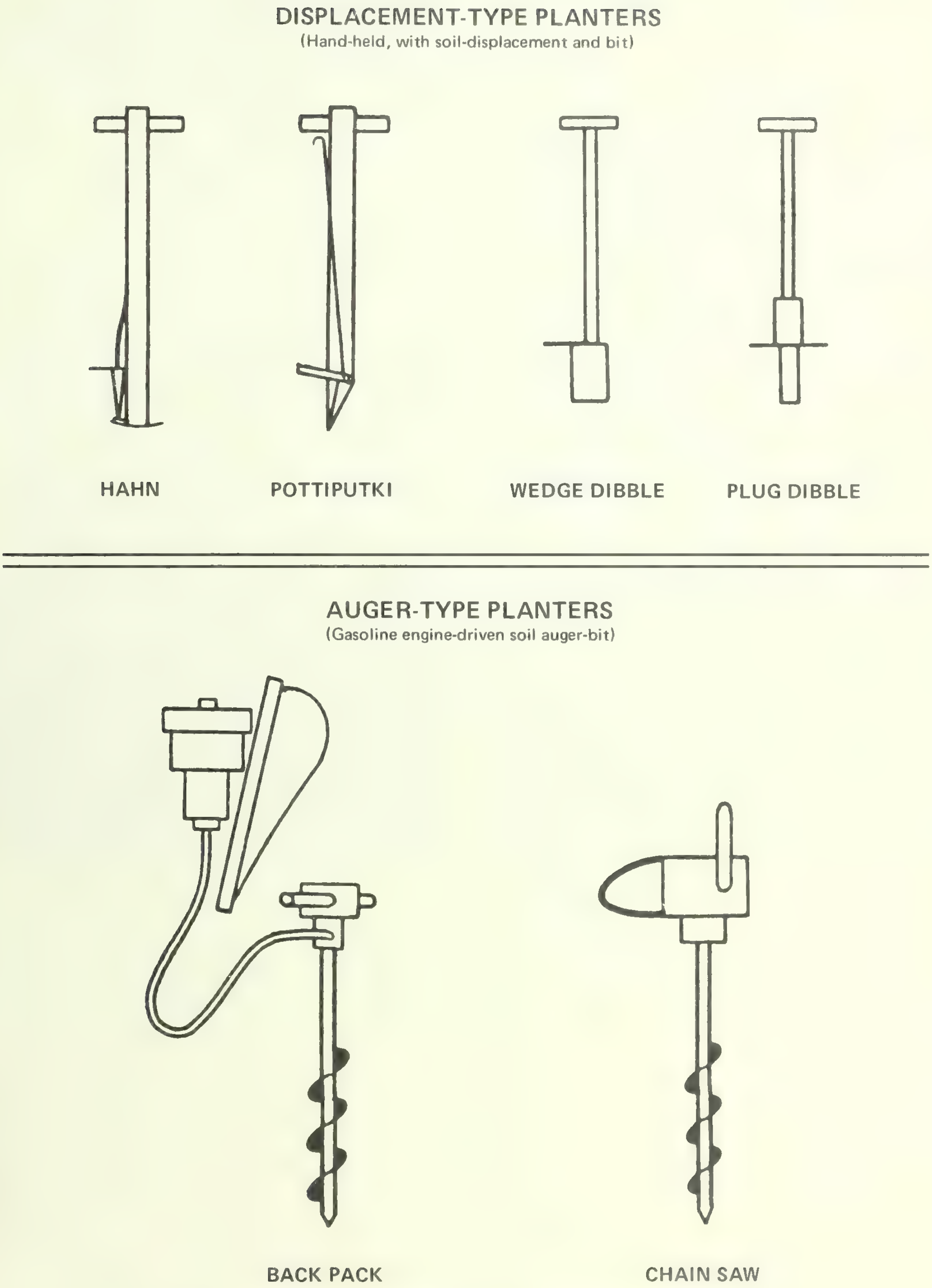

Figure 34. Hand planters for containerized seedlings.

this chapter. Clumps of trees can be transplanted using a front-end loader or a tree spade.

Discussion:

The front-end loader is efficient in digging up and moving pads of shrubs or trees, such as aspen. The pads must be replanted in an upright position, and guy wires may be necessary to anchor the trees. Because these trees will attract wildlife, it may be necessary to fence them until they are well established.

Tree spades have been developed for replanting small- to medium-sized trees. The spade mechanically digs, balls, transports, and replants trees and is available in different sizes. It is powered by its own gasoline engine, and the four digging blades are hydraulically operated. The largest of the spades will handle trees that are about 5-6 inches in diameter and will take a ball that is about 66 inches in diameter on the surface. Shrubs have also been successfully transplanted with the tree spade.

The spade can be towed with a 3/4-ton, 4-wheel drive pickup, which also carries a water tank to supply water to the tree spade lubrication system. A complementary trailer has been developed that will carry eight tree transplants. When using the tree spade, it is desirable to dig a hole that is larger than the size of the tree ball so that a small depression will be left after the tree is put in. This depression will catch available moisture.

A disadvantage of the tree spade is that its use is limited to slopes of 15 percent or less because the digging platform must remain level to insure that the tree is planted with its trunk vertical. Also, some trees having extremely long taproots cannot be transplanted successfully with the tree spade.

MIXED PLANTING

What are the general principles of mixed seeding?

When different sizes of seed are planted together, choose equipment that is adapted to mixed seeding and determine seeding rates based on seed size, purity, handling, and mixing capabilities.

Discussion:

Broadcast seeding accommodates different sizes and shapes of seeds and is useful if the seeds are covered in a subsequent operation. The Thimble Seeder and Hansen Seeder are two specific machines adapted to mixed-seed planting.

Some drills can also be used. For example, the rangeland drill, on which two seed boxes are attached, allows two seed sizes to be planted simultaneously, one seed type through each box. If a mix of seeds is drilled, it must be cleaned of trash to allow the seed to go through the drills. Proper seeding rates can be attained by adding carriers, such as rice hulls, with the seeds to dilute or help regulate distribution of seed.

Because mixed seeds may have different germination rates and periods of emergence, competition can be a problem. One way to minimize competition is to drill individual plant species in alternate rows. Spot seeding or site-specific seeding can also be done—but this technique usually requires hand-planting. Interseeders can be used to scalp away the topsoil where there is weed competition and then desired species can be seeded in the furrows made by the interseeder. Or, the vegetation specialist can drill grass seed in a site during one operation, and then come back later and interseed with other species.

What are the considerations of mixing seeds and transplant stock?

There are many advantages to mixing seeds and transplant stock, but a variety of planting methods may have to be used to minimize competition.

Discussion:

Advantages to this planting technique include:

• Irregular tracts with different site capabilities can be revegetated with clusters of plants.

• Highly erodible sites, needing a fast developing cover, can be planted with transplant stock, and remaining areas can be seeded.

• Sites with poor seedbed conditions, such as rocky surfaces, crusting soils, or toxic soils, require individual treatment, and this can be provided by mixed planting.

• If the species desired are in short supply, mixed planting maximizes the use of these species.

• Species to be mixed can be chosen to promote desired successional changes.

A recommended method of mixing seeds and transplant stock is to drill the seed, allow the plants to emerge, scalp them in certain spots, and then transplant into the scalps those species that are more adaptable to container, bare-root, or cutting cultivation. If competition from the seeded species is a problem, the grasses and transplants can be planted in alternate rows or in separate clumps.

Additional Information:

For more information on equipment for rehabilitation, refer to "Equipment for Reclaiming Strip-Mined Land," by Darrell Brown, USDA Forest Service, Equipment Development Center, Fort Missoula, Mont. Feb. 1977. No. 7728-2503, 58 p., illus.

For more information on planting methods, refer to:

"Plant Materials for Use on Surface Mined Lands in Arid and Semi-Arid Regions," USDA Handbook. Soil Conservation Service (SCS-TP 157), Lincoln, Neb. (in press).

"Restoring Big-Game Range in Utah," by A. Perry Plummer, Donald R. Christensen, and Stephen B. Monsen, Publication No. 68-3, Utah Division of Fish and Game, Ephraim, Utah. 1968.

Chapter 6
CULTURAL TREATMENTS

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Rehabilitation, by its definition, is a process initiated by man. The same definition holds true for cultural treatments. These treatments are often essential to establish a permanent plant cover and thus to assure that the rehabilitation process will succeed. The vegetation specialist plays a key role in advising the land manager or mine operator on the types of cultural treatments that should be used on a particular site. This chapter will discuss some of the principles the vegetation specialist should consider regarding cultural treatments. Treatments covered include irrigation, mulches, fertilizer, water harvesting, companion crops, and cultivation.

IRRIGATION

Irrigation, long used by western farmers, is also an important activity to consider when rehabilitating mined land.

When should irrigation be used?

Because irrigation is costly, it should be used as a temporary measure to enhance germination, help establish cover, and build up moisture in the soil. In some cases, irrigation can be used to aid in leaching salts from the soil. The vegetation specialist should keep in mind, however, that the plant community must eventually survive under natural conditions.

Discussion:

In general, irrigation should be considered when:

- The mined area will receive less than 10 inches of precipitation annually.
- Acquired water rights allow the use of irrigation water by the reclamation manager.
- Acquired water rights are sufficient.
- The water requirements of the plants dictate that irrigation be used.
- An area receives more than 10 inches of annual precipitation, and irrigation water is relatively inexpensive and available, such as from runoff or natural ponding. State water rights may affect the possibility of using these water supplies.

Leaching will be minimal or absent in the arid lands of the Southwest where spoils may be irrigated with an average of 12 inches of water per year.

How often and how much irrigation is necessary?

The amount and frequency of irrigation depends on the amount and intensity of natural precipitation, mine spoil make-up, density of plant cover desired, the species' water requirements, other applied cultural practices, and the availability of labor and funds.

Discussion:

- **Natural precipitation and mine spoil make-up.** It is known that the amount of rain absorbed by a soil depends on precipitation rate, infiltration rate, and water-retention capacity. If the precipitation rate is slower than infiltration, the soil will soak up all the precipitation up to its saturation point. If precipitation exceeds infiltration, surface runoff will occur.

It is also known that water readily infiltrates sandy soils, soils high in organic matter, and uncompacted soils. On the other hand, water does not readily infiltrate clay soils or soils low in organic matter. Sandy soils have less water-retention capacity; clay soils have greater water-retention capacity. These factors should be

balanced against one another to determine the optimum amounts, frequency, and rates of irrigation.

As one example, at the Navajo Coal Mine in northwestern New Mexico (grassland, elev. 5,200 ft, average annual precipitation 6 inches), the spoils are predominantly a clay type. Thus their water-retention capacity is high but problems occur with water infiltration rates. In this case, the spoils were classified as light, heavy, and medium, based on clay content. Heavy spoils had a clay content greater than 50 percent. Medium spoils were from 50-35 percent clay, and light spoils were below 35 percent. Watering regimes were established for each type of mine spoils as is shown in table 8. The table illustrates that the type of spoils greatly affects the rates of irrigation required to establish desired plants.

Information on optimum watering regimes for various kinds of mine spoils is not currently available in published form. The vegetation specialist should be aware that recommended rates on agricultural soils may not apply to mine spoils; however, because many spoils are a clay type, the information in table 8 should have wide applicability.

• **Density of plant cover desired.** Some ecologists have noted that it is inadvisable to try to attain a greater density of plant cover than that on adjacent undisturbed sites, because irrigation and other cultural treatments will be temporary. After they cease, the plant community must survive under natural conditions. It is difficult, however, to determine the plant density of an undisturbed area, since most regions of the West have been either overgrazed or disturbed in some way by man. Thus, other scientists claim that it is feasible to expect reclaimed lands to support and sustain greater plant densities. This problem is unresolved at present; however, regulations governing a particular mine site may set high density standards for plant cover.

• **Species' water requirements.** Certain warm season species—the gramas, blue stems, switchgrasses, for example—can be established with minimal watering. If these grasses are irrigated for a few days, they will germinate. A second moist period is needed 3 or 4 weeks after they emerge when secondary rooting is initiated. These roots will grow quickly—1/2 inch per day. So, by irrigating at the right time, certain grasses can be established that are normally difficult to root.

• **Labor requirements.** Note that in the case of the Navajo Mine, 12 inches of water were irrigated onto the spoils in the first year of revegetation, 2 inches in the second year, and none thereafter. In this operation, labor requirements and costs dictated that the irrigation period be no longer than this.

The reader is also referred to the section in this chapter on water harvesting, which discusses ways of taking advantage of natural precipitation, thus cutting down on man-hours and costs to irrigate using other water sources. Costs and labor requirements will be noted in the discussion of drip versus sprinkler irrigation systems.

What type of irrigation system should be used?

The two most frequently used irrigation methods for reclaiming mine sites are drip irri

Table 8. — *Watering regimes on mine spoils, Navajo Mine, New Mexico*

Spoil type	Hours duration	Frequency	Total amount applied
Light clay content	8	Every other day	12 inches the first year; 2 inches the second year; none thereafter
Medium clay content	6	Every 6th day	12 inches the first year; 2 inches the second year; none thereafter
Heavy clay content	4	Every other day	12 inches the first year; 2 inches the second year; none thereafter

(System Used: Laterals set 40 ft apart, with sprinkler heads 40 ft on the laterals; pressure regulating valves aided in delivering about 1 gal/min—an application rate of 0.08 inch/hr)

gation (fig. 35) and sprinkler irrigation. Factors such as the need to minimize water evaporation, site conditions, labor requirements, and costs should be considered when choosing between the two. Table 9 outlines the advantages and disadvantages of these two systems.

MULCHES

In the reclamation process, a second vital cultural treatment is mulching. A mulch is defined as any nonliving material placed or left on or near the soil surface for the purpose of protecting it from erosion or protecting plants from heat, cold, or drought.

When discussing mulches in reclaiming mined lands, a number of considerations should be addressed.

Why use a mulch?

Most researchers agree that probably the most effective way to stabilize an area of land is to establish plant growth as quickly as possible on the soil surface. Mulching will protect the site until plants become established and will often shorten the time for establishing adequate plant growth—if it is used with other good management practices.

Discussion:

The reasons that a mulch can aid in establishing plant growth are that it will:

- Prevent erosion, both by water and wind.

Table 9. — *Advantages and disadvantages of drip and sprinkler irrigation systems*

Type of irrigation system	Advantages	Disadvantages	Comments
Drip irrigation	Uses 1/3 less water	If water contains high sediment level, it will clog the lines, unless well filtered	Also called trickle irrigation Plant densities will be less; this can be a disadvantage, but not always
	Evaporation is minimal	If water is high in salt, salt deposits can build up around the emitter openings	Adequate filtering system crucial
	Amounts of water can be placed directly where wanted	Needs more maintenance than a sprinkler to check filtering system	Quality of water (sediment, salinity) a factor
	Especially useful on steep slopes, under power lines (because it is safer), between buildings, on critical areas	Labor intensive Less easy to move Shorter life span than sprinkler system	Three types of emitters: spitter (puts out a spray); single (puts small amount in local place); and bi-wall (plastic tubing with pin-prick opening to emit water)
	Moves salts away from plant roots Well suited for woody plants	Higher costs than sprinkler	A portable drip system, using a 500-gal tank has been developed by the Rocky Mountain Station at Albuquerque
Sprinkler irrigation	Less filtering needed	More evaporation will occur	Choose between solid set or movable
	Less expensive than drip	Need larger water supply	High plant densities possible
	Less labor intensive	Frequency of application higher than drip	
	Longer life		
	Easier to move, more flexible		

Figure 35. Second growing season using drip irrigation system.

• Facilitate infiltration.

• Inhibit evaporation (which may also slow upward movement of salts through spoils and/or soils).

• Provide proper soil temperatures.

• Be compatible with plant development, improve germination conditions, protect seedlings.

• Possibly add desired seeds while acting as a mulch.

• Reinoculate micro-organisms into mined spoils.

Of course, no one mulch will meet all of these criteria; thus, the vegetation specialist should determine which attributes are most important in his situation and choose the mulch that most nearly satisfies his needs.

Mulches will accomplish the following:

Water erosion control.

• Dissipate kinetic energy of raindrops.

• Lessen structural destruction.

• Lessen splash erosion.

• Lessen surface sealing.

• Allow more infiltration, less runoff.

• Lessen rill and channel erosion.

In the Southwest, mulching is particularly valuable in protecting seeded areas from the high intensity, short duration storms that often occur in the first summer rains.

Wind erosion control.

• Protect aggregates physically.

• Decrease wind velocity at soil surface.

• Help keep soil moist.

• Lessen particle movement.

Water conservation.

• Allow more infiltration, lessen runoff, and reduce evaporation from the soil surface because of the physical cover.

• Restrict air movement and allow higher relative humidity at the soil surface, and thus reduce water diffusion from the soil air out into the atmospheric air.

Temperature control.

• Lower or raise temperature by absorbing or reflecting radiant energy.

Typically, dark colored mulches can help aise spring temperatures and speed up the ermination rate, whereas light colored mulches an help lower summer temperatures, thus aidng areas where the soil surface can become too varm for optimum plant growth. It has also een found that in high elevation areas, mulches eem to reduce the problem of young seedlings eing lifted out of the ground by frost heaving; his is probably because the mulch creates a heat rap.

In general, a mulch will decrease the range of luctuation of temperatures.

Exception: With regard to darker colored mulches, a problem can arise if the soil is warmed by a mulch, followed by premature germination and inadequate soil moisture. In these cases, the seedling may start growing, run out of moisture, and then die.

Weed control.

- Best for shrub plantings or row plantings.

Germination and plant development improvenent.

- When broadcast seeding is used, best results re obtained by broadcasting the seed, covering vith soil, then applying mulch.

Vhat are some of the potential problems associted with mulches?

When considering mulches, a vegetation pecialist should realize that mulches can sometimes cause problems including nutrient and waste immobilization, germination inhibitation, and the attraction of unwanted organisms. He should choose a mulch after consideration of these potential problems.

Discussion:

Three significant problems with mulches are the immobilization of nitrogen (N), phoshorous (P), and sulfur (S); germination inhibiion; and the attraction of unwanted organisms.

Although not as much research has been done with phosphorus and sulfur, it is known that if an organic mulch has a carbon to nitrogen ratio of much greater than 25:1, it could potentially cause nitrogen deficiencies because the microorganisms attacking that organic matter are much more efficient in using any inorganic nitrogen that is in the soil than are the plants. Thus, these micro-organisms tend to decrease the availability of inorganic nitrogen and leave a deficiency for a short time. Included among mulches that have a very high carbon to nitrogen ratio are straw (fig. 36) and wood waste materials. The same principle can be applied to P and S.

Mulches high in nitrogen could produce a high ammonium concentration around germinating seedlings that could be toxic. Some organic mulches have phytotoxic materials that can be toxic to seedlings in some circumstances. And, mulches can cause slow germination and plant growth due to lower temperatures or water immobilization.

A third problem concerns unwanted organisms: insects, fungi, diseases, rodents, and weeds. For example, excelsior can attract mice, which then eat the seeds or the seedlings as they come up.

How is a mulch selected for a particular site?

Three general items should be analyzed when choosing a mulch—the site, the mulch effectiveness, and the vegetation desired.

Figure 36. Straw is an effective and economical mulch, but may cause nitrogen deficiencies.

Discussion:

When assessing site characteristics, look at:

- Topography.
  - Percentage slope
  - Aspect (does the slope face north or south, east or west?)
  - Roughness
  - Micro-slope and macro-slope aspects

These factors will affect the ability of the mulch to adhere to the site; aspect may influence the color of the mulch chosen—i.e., to either absorb or reflect heat.

- Spoil properties.
  - Texture, depth
  - Structure, surface roughness
  - Organic matter, infiltration, permeability

These factors will indicate what characteristics the mulch must ameliorate on the site; mulch choice will be influenced by these factors.

- Precipitation characteristics.
  - Intensity of storms
  - Total precipitation during a given storm
  - Seasonal distribution of storms

In other words, will the mulch be washed away in heavy rains? Will the mulch prevent moisture from reaching the plant/spoil materials?

- Needs for special equipment and cost of application.

When assessing a mulch, look at:

- Physical characteristics.
  - Color (important in terms of temperature)
  - Density (some mulches of low density will float down a slope during a storm)
  - Roughness
  - Durability, tenacity—will it stay in place where you want it to; will it attach itself to the soil or other organic material that is there?
  - Availability, distance (affects costs)
- Chemical characteristics.
  - Toxicity and decomposibility
- Manner of application (affects labor requirements).
- Cost.

When assessing the types of vegetation being cultivated, consider their germination rates and percentages, rooting habits, and drought resistance capability.

What are the pros and cons of various kinds o mulches?

Each mulch has typical properties. Their pro and cons should be judged against costs, type o vegetation to be cultivated, and the site to b mulched. Table 10 lists some of the more com monly known mulches, and their advantages an disadvantages. Also see figures 37-43.

Additional Information:

For a summary of methods and costs o common erosion control practices, includin mulches, see:

"Hydroseeding, Straw and Chemicals for Ero sion Control," by B. L. Kay, Agronomy Progres Report No. 77, Agronomy and Range Scienc Dep., University of California at Davis, 14 June 1976.

FERTILIZATION

Although fertilizers alone are not a cure fo nutrient-deficient soils and spoils, when they ar used in combination with proper spoil gradin topsoiling, planting methods, selection o species, mulching, and moisture, fertilizers wi greatly enhance the chance of revegetatio success. Fertilizers add nutrients to the soi which: (1) permit plant establishment; (2) spee

Figure 37. Hydromulching a steep slope.

Figures 38-43. Various kinds of mulches used in revegetation work. (Burns Sabey, Colorado State University)

Figure 38. Gravel applied at 135 tons/acre.

Figure 41. Straw jute.

Figure 39. Woodchip mulch.

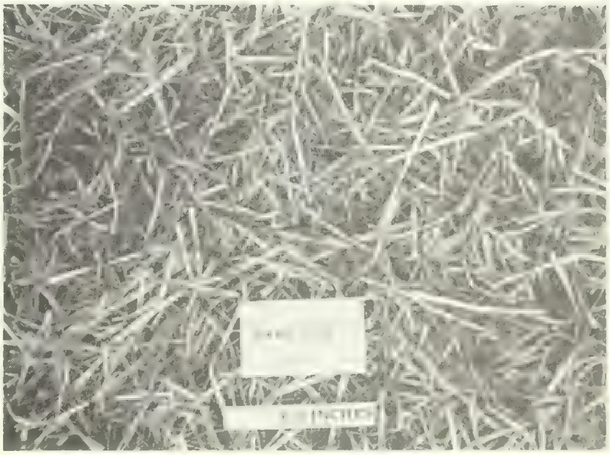

Figure 42. Straw applied at 2 tons/acre.

Figure 40. Excelsior blanket.

Figure 43. Cotton netting used to hold mulch in place.

Table 10. — *Advantages and disadvantages of commonly used mulches*

Type of Mulch	Advantages	Disadvantages	Comments
Crop residues: Straw or hay	Generally most economical Usually satisfactory under many circumstances	Weed seeds usually present; even hay seeds may be considered a weed on a particular site Straw may "wick-out" moisture from soils in very dry conditions, thus resulting in poor germination and seedling establishment	Anchor mulch, especially on slopes by crimping, or using plastic meshes, jute, chemical tackifiers Long-stemmed best, especially for crimping Uniform application important Generally, 2 tons/acre adequate In Utah, it was found that rotovating mulch 6-8 inches into soil increased grass seedling survival Can be spread with modified farm manure spreader
Native grasses; prairie hay	Adds desirable native species seeds to area and mulches at same time	May harvest weeds along with native species	
Wood residues: sawdust, woodchips, bark, shavings	Protects surface Adds organic matter No weed seeds More fire resistant than straw Long lasting Easy to apply Chips resistant to wind movement	Shavings and sawdust blow Nitrogen deficiency Packing may occur resulting in less aeration May float on running water May prevent precipitation from reaching spoil	Chips: 2 tons/acre usually adequate; chip size, 1/2 inch to 1/50 inch
Plastic film	Excellent vapor barrier Good weed control Light-colored, perforated, found effective in New Mexico: soil temperature in summer 18° F lower than in soil with no mulch	Labor intensive High cost	Information on temperature effect varies Color is important because of reflection, absorption
Fiber tackifiers and soil binders	SBR Styrenebutadiene and SS Super Slurper have been found to be very absorbent and thus help provide water	Quite expensive Must be applied correctly in order to have maximum effectiveness With SBR Styrenebutadiene and SS Super Slurper premature germination may occur In high wind areas, it can solidify, break into pieces and blow away	Typically added into water carriers; can also be added with seed slurries 500-1,000 lb. of solids/acre usually sufficient, dilution rates of 5:1-7:1 optimum
Rocks, gravel, pebbles	Effective at specific sites Are permanent—do not disintegrate	Smaller than 1/12 inch in diameter not good for wind erosion	Choose sizes greater than 1/12 inch in diameter Must nearly cover entire ground surface—1-2 inch thick is effective control (135 tons/acre = about 1 inch depth)
Mixtures	Add micro-organisms to soil over short and long term (Ex.: straw and bark)		

Table 10. *(Continued)*

ype of Mulch	Advantages	Disadvantages	Comments
lydraulic nulching	Labor costs low Typical green color allows operator to get uniform distribution Hydromulching and hydroseeding can be done at the same time, if it is impossible to do the two operations separately Wood cellulose fiber mixed with seed and fertilizer can be sprayed on steep slopes	Of little value unless it adheres to the soil surface and remains intact during rainstorms, wind Hydromulch with fiber improves germination, but does not improve production When hydromulch and hydroseeding are done together, seeds may not have adequate soil contact	Application rate of 1,500 lb/acre appears adequate for most situations; may need more for quite steep slopes May need to add N to hydromulch to compensate for C:N ratio of mulch chosen Always put some seed in mulch Hydroseeding and hydromulching together should be reserved for special cases when moisture is sufficient to keep the seed moist for 2-3 weeks after seeding
abric or mats: ite, excelsior, woven, aper, plastics, nets	Especially useful on steep slopes Nets good in high wind areas	Expensive: 4-5 times more than tacked straw High labor input for anchoring Not effective on rough surfaces or rocky areas Erosion from beneath may be a problem	Used only on limited critical areas because of cost
lanure and ewage sludge	Can protect soil surface and adds nutrients, such as N, P, K, S	When used alone, it becomes wet, then dry, can lose much of N through volatilization of ammonia	Needs 5, 10, 15 tons/acre in order to protect soil On bentonite spoils, a grass establishment study showed that an application of wood chips as mulch and sewage sludge as N supplier was more effective than a high application (400 parts per million) of inorganic N
sphalt	Rapid-curing asphalt keeps straw and other materials in place Slow-curing asphalt allows for growth of seedlings before it cures Coats surface, remains intact 4-10 weeks A stabilizer for straw Nonporous, and conserves water underneath it Some plants react positively to it	Nonporous, thus causes surface water to run off Some plants react negatively to it	Make decision based on type of asphalt (slow, medium, rapid curing) desired Make decision based on reaction to asphalt by plant species desired 1,200 gal/acre an average application Typically, heated and spread by spraying Apply from top of slope down, so impermeable caps are built on clods of soil down the slope, leaving sides free for seedlings to come out of and to absorb water
esin emulsion in ater	More porous than asphalt Insoluble in water Resistant to weathering		600 gal/acre good against wind erosion Often considered superior to asphalt
atex emulsion	Resistant to erosion	Limits water penetration Some studies indicate it is less effective than some other mulches	

up plant growth; and (3) maintain plant productivity. On mine spoils, fertilizer will speed up the production of biomass, which will provide long-term nutrients to the plants.

What criteria determine if a fertilizer should be used?

Several factors influence the decision to use fertilizer: (1) the nutrient needs of the plant species to be planted; (2) known nutrient deficiencies in the soil/spoil; (3) effect of fertilizers on soils/spoils; (4) necessity of refertilization; (5) cost; and (6) available soil water.

Discussion:

Some plant species have less nutrient needs than others and thus may not require fertilizers. Plant physiologists should be able to advise on the nutrient needs of the desired plant species.

Soil/spoil nutrient deficiencies are determined by field and lab soils tests. Work with the soils specialist to determine this factor.

Effects of fertilization on soils/spoils are best determined by running field plot studies.

What nutrients are most commonly lacking in spoils?

Mineral deficiencies on disturbed lands are dominated by nitrogen (N) and phosphorus (P) deficiencies. The vegetation specialist should be aware of the characteristics of these deficiencies, and the methods used to detect them. It should also be recognized that organic carbon content is generally low in spoils and may be biologically inert.

Discussion:

Nitrogen. When looking at the possibility of a nitrogen deficiency consider:

- An N deficiency is often a limiting factor in plant productivity, rather than seedling establishment.
- Subsoils and geological materials will probably be extremely nitrogen deficient; topsoils will usually contain adequate nitrogen.

> Exception: Some shales, the cretaceous and tertiary shales, for example, are fairly high in nitrogen; however, it is thought that after several years of plant growth on these shales, the N may be used up and the plant system may become N deficient.

- Nitrogen soil tests are of limited value in detecting N deficiencies on geological materials and on subsoils; however, they are recommended as a good starting point. When in doubt, strip N on field test plots at various rates to determine response to N fertilization.
- There are natural N inputs from precipitation onto disturbed lands (2-3 lb/acre/yr in desert areas; 4-5 lb/acre/yr in the mountains; 6-10 lb/acre/yr on the plains). But this process adds only a relatively small amount of N per year.
- Indications of N deficiencies: Sickly yellowish-green color; chlorotic foliage; distinctly slow and dwarfed growth; drying up of or "firing" of leaves, which starts at the bottom of the plant and proceeds upward. These, however, are only indications; other factors may be at work. Soil and plant-tissue tests may be needed to confirm observations.

Phosphorus. When looking at phosphorus deficiencies consider:

- P deficiencies limit or prevent seedling establishment; this occurs to such an extent that plant failure is often attributed to lack of moisture in the soil, when, in fact, the soil is so P deficient that the plants do not grow enough to extend their roots down to the available moisture supply.
- P soil tests are usually reliable for detecting phosphorus deficiencies.
- Other indications of P deficiencies: purplish leaves, stems, and branches; slow growth and maturity; small slender stalk or lack of stooling; low yields of seed.
- P deficiencies are most readily seen in seedlings.
- Losses of P by leaching or volatilization are usually considered to be small.

What steps are taken to correct a P deficiency?

Add P in the form of P_2O_5 (phosphorus pentoxide), using quantities based on the extent of the deficiency and following recommended procedures for use of the fertilizer. The following recommendations can be used until on-site experience or research shows that other methods are more appropriate.

Discussion:

- Use relatively high amounts of P_2O_5 on drastically disturbed lands that test deficient in

ant available P; 100 lb/acre P_2O_5 on coarse-xtured soils and 200 lb/acre on fine-textured ay soils have been recommended.

• Consider using commonly available P urces. Examples: (1) Triple Superphosphate -46-0 = 46 percent P_2O_5). Superphosphates ay range from 42-53 percent P_2O_5; the nota-on 0-46-0 means that in a 100-lb bag of fertil-er, there are 0 lb of N, 46 lb of P_2O_5, and 0 lb K (potassium) (also see fig. 44); (2) 11-48-0 mmonium phosphate); (3) 16-20-0 (am-onium phosphate); (4) 21-53-0 (diammonium osphate); (5) sewage sludge; (6) manure. hen using sewage sludge or manure to meet N quirements, enough fertilizer will probably be lded to also meet phosphate requirements.

• Amounts applied are related to the percent-e P in the fertilizer; i.e., to apply 100 lb/acre P_2O_5 as 0-46-0 requires 217 lb of 0-46-0 rtilizer.

• Do not use less soluble P sources on neutral d calcareous soils. (Superphosphates and am-onium phosphates are soluble P sources.)

• Mix phosphate into the soil before seeding r best results. Especially in the fine-textured ils of arid and semi-arid regions, it is important get phosphate into the soil for the seedlings grow into.

• Phosphorus fertilization has a long-lasting fect, and thus the soil/spoil may need only one application.

hat steps are taken to correct an N deficiency?

Many sources of N are available; soil tests and n-site experience will help the vegetation pecialist recommend the best sources for pecific situations.

iscussion:

• Whenever possible, save dark topsoil be-use it usually contains adequate N for plant stems.

• When N is deficient, apply 40-50 lb of /acre to disturbed sites. When 2 tons of straw er acre are used as mulch and crimped into the il, 50-60 lb/acre of N may be required in addi-on to the above N. With sufficient moisture, 80 of N/acre (500 lb of 16-16-16) have been dded successfully.

• Sources of N fertilizer include (1) am-onium nitrate, 33-0-0 (most commonly available, usually the least expensive); (2) ammonium sulfate; (3) urea, 43-0-0 (a highly concentrated N source, that can be subject to volatilization loss when broadcast on the surface; costs are comparable to 33-0-0); (4) ammonium phosphates, 16-20-0, 11-48-0, 21-53-0; (5) sewage sludge; (6) manure. (Sludge and manure are alternative N sources where available and when transportation costs can be afforded.)

• Amounts applied are related to percentage of N in fertilizer; i.e., to apply 50 lb N/acre would require 150 lb N/acre as 33-0-0 or 238 lb of N fertilizer as 21-0-0.

• In areas where late fall seeding is done, the optimum time to apply N is after germination in the spring; in the spring seeding, N can be applied at the time of seeding, but keep N from contact with the seed.

• Nitrogen is quite water soluble, so it can be surface applied; it is best to apply N before expected moisture.

• In some situations where annual weeds may offer stiff competition to perennial establishment, N fertilization may be delayed until the

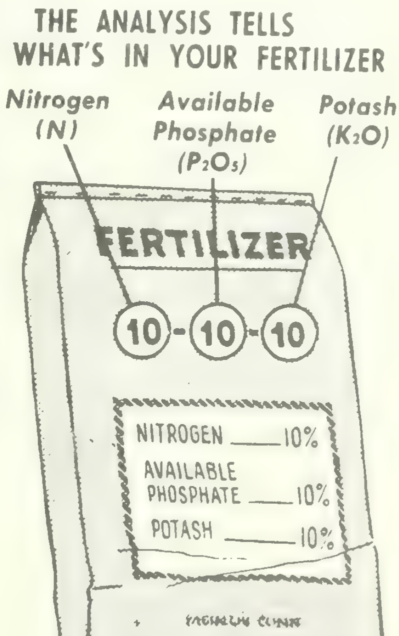

Figure 44. Fertilizer labeling gives nutrient content. (The Fertilizer Institute)

second growing season. Once perennials have been established, annual weeds usually cannot compete.

• Nitrogen fertilization effect is short term; repeated applications may be necessary. Visual observations are usually the best guide to N refertilization needs although soil tests are another indication. (Also see chapter 7.)

What kind of maintenance fertilization will be needed?

Phosphorus can be applied once (this should be sufficient to start P cycling); however, N may have to be added every 2 or 3 years on certain N-deficient soils.

Discussion:

• Certain sites may need substantial amounts—up to 500-700 lb/acre of N. This may entail adding 30-40 lb/acre of N every 2 or 3 years for 10 or even 20 years. Expense and labor availability are concerns here. Such sites include those with coarse-textured soils, subsoils, geologic materials, or high precipitation.

• Alternatives to applying N: (1) Replace topsoil whenever possible; (2) choose N-fixing plant species, although in drier areas, few of these species are available; (3) plant less N-demanding species (such as rabbitbrush, sagebrush, lodgepole pine).

• Consider maintenance N when foliage is a light green color and/or there is a substantial reduction in ground cover.

> Exception: Consider limiting N maintenance if goal is to encourage invasion onto site of less N-demanding species.

• When in doubt, apply N to field test plots; if site receives moisture, a response should be seen in about 10 days.

What other nutrients may be lacking in the soils/spoils?

Nutrients are divided into macronutrients, which plants need in large quantities, and micronutrients, which plants need in small quantities. Phosphorus and nitrogen are macronutrients. Other macronutrients are potassium, calcium, magnesium, and sulfur. Soil tests will indicate if these are lacking in the soil. Among micronutrients are boron, manganese, copper, zinc, iron molybdenum, and chlorine.

Discussion:

Soil tests, plant-tissue tests, observable deficiency symptoms in plants, greenhouse tests, and field test plots are all methods used to discover nutrient deficiencies. The effects of micronutrients on vegetation establishment have not been fully evaluated. In addition, keep in mind that the acidity or alkalinity of the soil will affect the ability of the plant to take nutrients into its system.

> Exception: Toxic levels of nutrients are also possible; a familiar example in the West is saline soil, which bears too many mineral salts, including nutrients like calcium and magnesium (a Ca/Mg ratio exceeding 1:10 may present problems). Again, soil tests will detect this problem, although the effects of toxic amounts of nutrients, especially micronutrients, are not fully known.

How is fertilizer applied?

Some suggestions for N and P application have already been given. In general, application methods depend on the plants, soil, climate, date and rate of application, kinds of fertilizer and equipment available. The goal: To get the proper amount of fertilizer in the soil where it will do the most good.

Discussion:

Broadcasting, banding along the row, deep drilling, plowing, drilling with seed, foliar application, side dressing, bedding, starter solutions, top dressing, and irrigation are all methods of applying fertilizer.

Are fertilizers dangerous to humans?

They can be; consult publications available from the Fertilizer Institute, 1015 18th Street N.W., Washington, D.C., covering safe handling of various kinds of fertilizers. District offices of the Occupational Safety and Health Administration (OSHA) also have information for safe handling of fertilizers.

Additional Information:

For more information on the uses of fer

zers in specific situations, consult local Soil Conservation Service offices.

Also consult:

"Soil Fertility and Fertilizers," by Samuel L. Tisdal and Werner L. Nelson, MacMillan Publishers, N.Y. Collier MacMillan Publishers, London, 1975. 694 p.

"Soil Testing and Plant Analysis," by Leo M. Walsh and James D. Beaton (ed), Soil Science Soc. of Amer., Madison, Wisc. 1973. 491 p.

"Western Fertilizer Handbook," Soil Improvement Committee, Calif. Fertilizer Assn., Interstate Printers and Publishers, Inc., Danville, Il. 1975. 250 p.

WATER HARVESTING

Water harvesting is the practice of using the landscape to collect and accumulate runoff water and concentrate that moisture in a plant-growing zone. First practiced by ancient man, it continues to have application today in arid regions of the world. In nature, the principle of water harvesting is demonstrated by greater plant densities near gullies and depressions in arid lands.

When should water harvesting be used?

Water harvesting is appropriate in areas that receive less than 15 inches of precipitation annually; it is also useful in any spot where rainfall is the major limiting problem associated with revegetation, and irrigation water is scarce.

Discussion:

Snow and rain will both be trapped by water harvesting methods. The results can be 2-3 times more biomass growth from plants exposed to water harvesting than from those that are not exposed to this technique.

What methods of shaping the land result in water harvesting?

Various methods can be used; for example, a water-collection area several feet long can be shaped, or the land can be pitted, contoured, gouged, or chiseled. All of these methods can trap precipitation and direct it into a plant-growing area.

Discussion:

The area to be set aside for collecting water varies, depending on rainfall amount, intensity, and timing, as well as soil infiltration and slope.

For example, if rainfall amounts and intensity are high, a smaller area will be needed as a water-harvesting zone because water runoff will be substantial. In addition, if the infiltration rate of the water-collection site is low, a smaller water-collection area will be needed to get the necessary runoff. These factors will help the vegetation specialist determine the ratio of water-collection area to plant-growing zone. These ratios can range as high as 30:1; on mine sites a typical range is 3:1 to 6:1.

Generally, if the vegetation specialist consistently observes pools of water or gullies originating in the plant-growing zone, the water-collection area may be too large. Preferably, the moisture accumulated will readily absorb into the plant-growing zone.

Which methods work best in mined areas?

Pitting, gouging, or contouring are generally better methods to use on mine sites than is a long water-collection bed. The object in using any of these methods remains the same, however: to increase runoff from the water-collecting zone and increase infiltration in the plant-growing zone.

Discussion:

Usually the slopes on the mine site are so steep that the water collected in long beds will not be distributed evenly onto the plant-growing zone. Long water-collection beds work satisfactorily only on areas where the terrain is flat. Caution should be exercised when considering the use of contour trenches on spoils that tend to settle or spoils that are subject to piping as this might cause slope failures or increased erosion due to water concentration.

Various chemical treatments, including paraffin, silicone emulsion, and polyvinyl acetate, have been used to prevent penetration of water into the water-collection area and thus to increase the amount of water running off into the plant-growing zone. Some of these additives will also aid in stabilizing the water-collection zone's surface. The decision to use a chemical sealing material should be based on the soil characteristics of the site being used as a

water-collection zone. For example, if the soil/spoil is a high sodic, clay type, it tends to seal itself and thus the addition of a chemical sealant does not increase water runoff. In these cases, the cost of using the chemical is not justified.

On the other hand, if the soil is a sandier type, reducing infiltration by using a chemical sealant is important. In these cases, a 25-percent greater plant establishment has been reported on treated areas as compared to nontreated areas.

Mulching will aid in water harvesting because it will improve infiltration and reduce evaporation in the plant-growing zone. Noticeable results have been achieved by using a vertical mulch, which is a method of gouging a narrow slit in the ground near the plants and crimping straw into it to increase infiltration. In addition, both straw and bark have been successfully used as a mulch.

A disk plow can be used to contour the mine slopes; the contour should be broken about every 15 ft. The recommended size of the contours is 1-ft deep and 15-inches wide. A large (5 ton) multi-disk plow may also be used if alternate disks are removed and the largest available blades installed. Contours, under most situations, should not be more than 10 ft apart to prevent accelerated gully erosion.

What are some of the drawbacks of water harvesting?

The expense of shaping a water harvesting site, the unsightliness of large water harvesting areas, difficulties with chemical sealants, the difficulty of getting effective contouring to maximize moisture collection and yet not cause erosion, and the possibility of harvesting salts are all potential drawbacks of water harvesting.

Discussion:

Regarding unsightliness, the principle the vegetation specialist should keep in mind is that even though a parcel of land is being sacrificed to provide more moisture to a smaller plant-growing area, it is expected that once these initial plants are established, plant invasion onto the water-collection site will begin.

Chemical sealants must be monitored to determine whether: (1) they are breaking down too slowly, and thus preventing plant invasion on the water-collection area; or (2) they are breaking down too quickly and thus not allowing enough water harvesting to establish plants in the plant-growing zone.

It is important to tailor the size of the harvesting area to fit the runoff potential of the site. Factors such as slope, infiltration, and rainfall intensity must be considered so that the harvested water will remain in the plant-growing area. If runoff volume from the harvesting slope exceeds retention volume of the plant-growing area, erosion will be accelerated. Careful calculation of the above, taking into account the maximum storm size expected, is critical to success. Contour furrows spaced greater than 10 ft apart, on slopes greater than 15 percent, can accelerate gully erosion. Unbroken contour furrows should not be used.

The first moisture received from a water-collection area in a mine site may contain salts; however, subsequent moisture contains less salt. The salinity of mine spoils would influence the extent of this potential problem; research is being conducted to further study this factor.

COMPANION CROPS

The general term "companion crops" is synonymous with nurse crops or cover crops. A companion crop (also called green mulch) is an annual crop such as peas, barley, or oats that i seeded with perennial species to modify micro environmental conditions during the initial establishment period. A preparatory crop is seede before the perennial forage; then the perennia species is seeded directly into the residue lef from a preparatory crop without further seed bed preparation. Such crops act as temporar stabilizers of the site while the permanent vegetation establishes.

What are the advantages and disadvantages of companion and preparatory crops?

Although both have potential for use o mined sites, certain climatic regions and topogra phies are more suited to one than to the othe. Decisions on companion crops should be base on site-specific considerations. Table 11 outline the basic advantages and disadvantages of th two types.

Discussion:

When using companion crops in minelan

Table 11. — *Companion and preparatory crops—their advantages and disadvantages*

[It]em	Companion crops	Preparatory crops
[Ad]vantages	Reduces wind and water erosion Reduces weed competition Protects forage species from wind and severe temperatures Will produce a crop of value prior to development of perennial forage species	Protects topsoil until a permanent species can be established Controls wind and water erosion Reduces evaporation from around seeds and establishing plants Smothers out germinating weeds Reduces or prevents a new crop of weeds
[Di]sadvantages	Can result in severe competition for moisture and light required by the desired perennial forage species	Reduces seed contact with mineral soil if residue is too thick Some cases of phytotoxins left from preparatory-crop residue Can provide competition from volunteer seedlings if preparatory crop permitted to produce seed
[Co]mments	Not recommended for semiarid or arid regions where moisture shortages are likely during establishment period, or on soils of low fertility Especially beneficial in sub-humid and humid regions or with irrigation Where irrigation is available, competition will be lessened; however irrigation also increases changes of success of desired vegetation, even without companion crops. In this care, companion crop has advantage in windy or high temperature sites.	In general, preparatory crops have more application in dry climates of West

eclamation, several considerations should be ‹ept in mind:

• Companion crops to some degree, but es- ›ecially preparatory crops, will help stabilize the oil/spoil complex after mining by controlling erosion.

• A companion or preparatory crop may pro- ride needed microclimate modifications, which vould help establish perennial seedlings; how- ever, as noted earlier, supplemental water is usu- lly necessary to counteract competition for soil noisture in the semi-arid and arid West.

• When choosing species to work together as companion crops, consider combining groups of species, such as fast establishing, short-lived species with slow establishing, long-lived species, or warm-season species with cool-season species.

• When seeding companion crops in a dry climate, use a low seeding rate (for example, 7-10 lb/acre of oats).

• Stubble from a preparatory crop acts as a temporary site stabilizer. When the desired species is seeded into the stubble, there is less moisture competition because the preparatory crop is not alive; however, it provides erosion control and lowers evaporation and surface temperatures.

CULTIVATION

Cultivation is used as a cultural treatment after the establishment of the plant, particularly for shrubs and trees. Cultivation will mix the soil material and provide weed control. It will also break up the surface crust, which will improve

water infiltration, promote soil aeration and increase the root system by maintaining optimum aeration and fertility.

When should cultivation be done?

Cultivation should be done on dry soil and often enough to keep the area fairly free from weeds during vegetation establishment.

Discussion:

Summer fallowing is recommended; if weeds are controlled for 6 months after planting, plant growth will increase substantially.

What techniques are adequate for cultivating?

Implements such as deep moldboard plows, tooth harrows, and roto-tillers may be used.

Discussion:

When using a roto-tiller, it is advisable to remove a few of the prongs so the implement stays at least 6 inches from the shrub or tree.

Another technique is strip cultivation; it is recommended on relatively harsh sites, such as bentonite clay spoils, because it conserves moisture. In this technique, roto-till a strip in an area that has been seeded with grasses and saltbush; plant trees in the strips; and cultivate the strips every spring. Use a chemical emergent treatment within the 6-inch area near the stem of the shrub or tree to prevent weed encroachment.

Chapter 7
IANAGEMENT PLAN AND MONITORING

napter Organizer: Ardell J. Bjugstad

ajor Contributors: Ardell J. Bjugstad, Teruo amamoto, Daniel W. Uresk

Proper management and monitoring of the re-aimed site are vital to maintaining its stability. onsiderations of protection needed at the site; ethods to evaluate and nurture the vegetation source; and provisions for special emphasis eas should be included in the management an. Once this plan has been set, industry ersonnel and/or the land-management team are sponsible for monitoring the site to make sure at the agreed-upon goals are being adequately et.

PROTECTION OF THE RECLAIMED SITE

/hen should a reclaimed area be protected?

Whenever the vegetation on the site may be ıreatened by livestock, wildlife, invading eeds, or human traffic, the rehabilitated area ıould be protected, at least temporarily.

iscussion:

Animal use of rehabilitated sites can be com-atible with vegetation establishment and main-nance. Management plans that include use of e site by animals can be successful as long as e management team realizes that reclaimed eas may be more sensitive than adjacent range-nd, and that special standards govern their habilitation. For example, seeded areas some-mes will attract animals such as deer in umbers sufficient to damage the stand. odents and rabbits can also damage the vege-tion. These animals are attracted by the lush-ess and palatability of the planted vegetation. hus, if pressure from animal invasion becomes too great, steps should be taken to protect the site.

What techniques are recommended for protecting the site against livestock?

A variety of techniques are successful; however indirect methods of keeping livestock away from a site are less costly than direct methods.

Discussion:

Indirect methods for protecting a site against livestock include:

- Adding less palatable species to the seed mixture;
- Salting away from the seeded area—no closer than one-fourth mile;
- Providing permanent water away from the seeded area; fencing out nearby water;
- Adjusting the use of livestock on the site to allow plants to mature by using a temporary alternative area for grazing, or by requiring non-use during seedling establishment;
- Moving livestock off the area when allowable use is reached on the revegetated site.

Direct methods include:

- Barriers. Metal or wood devices, varying from the common barbed-wire fence to brush piles (fig. 45), are effective.
- Repellents. Those used to repel wild ungulates have some effectiveness on sheep and cattle (see section on wild animals); however, specific repellents to discourage livestock use have not been fully developed.
- Herding. This requires the use of herders to keep animals contained on areas other than those recently reclaimed.

What techniques are recommended for protecting the site against animal wildlife?

Again, various techniques are successful; the vegetation specialist should employ those that are most effective in preventing overuse of the vegetation as food and habitat.

Discussion:

Indirect methods for protecting a site against wild animals include:

- Using plant species that are undesirable to deer and elk;
- Using plant species that mature about the same time as native species;
- Avoiding hay as mulch where it may attract big game;
- Controlling the deer population through hunting permits, particularly in localized areas during plant establishment.

Direct methods for protecting a site against wild animals include:

- Barriers (fig. 46). Metal, plastic or wood devices, varying from woven wire fence to brush piles, which prevent browsing can be used. Four to six inch diameter plastic tubing placed over trees or plants to be protected have been effective in the Northeast. Woven wire fences 8-ft high are recommended to exclude antelope, deer, and elk. Slash piles over seedlings or plantings discourage browsing while the plants gain height.
- Repellents (fig. 47). The effectiveness of repellents depends on the plant species to be protected and the availability of other vegetation in the area. It has been found that repellents may not be effective when the vegetation is being irrigated. Apparently, the lushness of the vegetation is so attractive to the animals that the repellents do not deter them. Some repellents and the animals they repel are listed in table 12. Specific repellents to discourage rabbits and rodents have not been fully developed.
- Herding. This can be achieved with noisemakers, such as metal cans or acetylene guns. Lights and mirrors have also been used, as have tethered dogs.
- Poisoning. Small mammals can be controlled by poisoning. Check State and Federal regulations on use of poisons.
- Encouraging predator invasion. Roosts, rock piles, etc., will provide a habitat for predators and thus control small mammal populations.

When and how must an area be protected against weeds?

Weeds may have to be removed from a rehabilitated site for a variety of reasons: they present a fire hazard, especially along roads; are esthetically displeasing; are noxious; or provide too much competition with desired plants. Both mechanical and chemical means can be employed. In general, chemical means should be used only in highly selective situations such as for control of noxious weeds.

Discussion:

Mechanical means include:

- Mowing. Weeds must be kept down below 6 inches;
- Shredding. Needed for woody-type weeds;
- Cultivation. Last resort due to wind and water erosion and cost of operation.

Chemical means involve the use of plant regulators, which are any substance or mixture of substances that affect physiological action, growth rate, or other behavior of plants. Plant regulators include:

- Herbicides;
- Defoliants (any substance or mixture of substances used to cause leaves or foliage to drop from plants);
- Desiccants (any substance or mixture of substances used to accelerate the drying of plant tissues artificially).

Table 12. — *Common animal repellents*

Compound	Animals repelled
Tetramethylthiuram disulfide	Rodents and d[illegible]
Bone tar oil	Carnivores
9, 10-anthraquinone	Birds
4, aminopyridine	Birds
0, 0-Dimethyl-0-4-methylthio-m-tolyl phosphorothioate	Birds
3-chloro-p-toluidine hydrochloride	Birds

Figure 45. Brush can be used on the site to protect young seedlings during establishment.

Figure 46. Deer-proof fence.

Figure 47. Applying repellent next to deer-proof fence.

Caution: Herbicides can cause injury to humans, domestic animals, desirable plants, fish, and other wildlife. In addition, they should not be used over or directly adjacent to irrigation ditches, ponds, lakes, streams, or homes. Thus, it is important to note that all directions and precautions on the container label be closely followed. Federal, State, and county laws and regulations governing the use of herbicides must also be adhered to. This will be the responsibility of both the land manager and the applicator. Before using any chemical, check to make certain the chemical is registered for the planned purpose.

Additional Information:

Consult with your regional reclamation specialist, local Soil Conservation Service offices, the USDA's Cooperative Extension Service, or pesticide dealers for specific information on the best chemical means for protecting the site from weeds.

When should insecticides be considered?

Before making any attempt to control insects, you should know (1) the name of the insect you want to control; (2) the dangers of using chemicals to control insects; and (3) whether the harm caused by the insects is sufficient to warrant use of an insecticide.

Discussion:

If you do not know the name of an insect, a county agent can help. The vegetation specialist should also realize that some insecticides are highly toxic; it is absolutely necessary to read and follow all warnings on insecticide labels. In addition, Federal and State regulations have established limits on insecticide use. Follow product directions for application to make sure these standards are adhered to.

What kinds of insecticides are recommended?

Sprays and dusts can both be used; sprays have proved as effective as dusts, provided the correct amount of insecticide is applied per acre.

Discussion:

Sprays have certain advantages over dusts: they drift less and can be applied in winds up to 10 mi/hr; less labor is required for handling liquids than dusts; sprays are less apt to be washed off by rain. Also note that nearly all insecticides are known by more than one name. Always check the label to make sure you are buying the correct chemical.

SUCCESSION

Because reclamation efforts ultimately aim at restoring the land to a self-sufficient state, natural succession becomes one of the primary goals of the revegetation process. Thus, during reclamation and postmining, the vegetation specialist should be able to determine whether or not desirable plant succession is taking place.

What methods can be used to study plant succession?

Two direct methods can be used: plant succession studies on the same plot; and plant succession studies done by comparing two different areas.

An indirect method is to relate wildlife preference by the type of wildlife and livestock inhabiting the area to the kind of plant succession that is taking place. Information on the types of herbage preferred by various animals is available from wildlife specialists.

Discussion:

Plots on the same area:

- Permanent plots are established, labeled, and measured at intervals over several years. Criteria measured can include: plant frequency, diameter, height, canopy cover, denisty, mortality, and biomass of the plants. Measurements can be done manually, by photographs, or through historical and file records, including vegetation maps. Manual studies are the most accurate way to measure succession; they also require more labor.

In comparison studies, two approaches can be taken:

- Measure two different sets of plots, each in a different locality, but with the same ecological conditions, and compare succession trends.
- Infer from records on other studies of disturbed sites what kind of succession is taking place on the rehabilitated site; dates of disturbances must be known to make a useful comparison.

PRODUCTIVITY

Measures of plant productivity are also im-
rtant in analyzing the success of the recla-
ation program.

hat productivity measurements can be used?

Frequency of plant occurrence, changes in orphological characteristics, and volume easurements can all be used (fig. 48-50).

scussion:

Frequency of occurrence:

• Canopy cover of a plant species on study ots can be measured.

• Certain plants within study plots can be unted and compared either over time or with other study plot (example: number of shrubs r acre).

Changes in morphological characteristics:

• Identify the morphological characteristic at best applies to the species being measured.

• For grass species, morphological character-ics can include the number of leaves, length of aves, length of flowering columns, length of ikes, and number of flowering columns per ımp or per area.

• For trees, current annual growth can be termined by measuring twig length or by rvesting the twig and determining length to eight relationship.

• For shrubs, measure twig length, length to eight relationship, leaf length, or leaf width.

Volume measurements:

• A simple volume estimate can be obtained measuring the length, width, and height of nall trees or shrubs on the site, especially ants that produce a large amount of side anching.

• A more accurate volume measurement is to late volume, as measured by length, height, ıd width, to the weight of the shrub. This is one by harvesting, measuring, and weighing proximately 20 plants of the same species. ased on these figures, the weight of other rubs can be estimated from volume measure-ents taken in the field.

ow is plant harvesting done?

If harvesting is used, choose a random site or presentative area on the site and harvest by

Figures 48-50. Measures of plant productivity are used to analyze the success of the reclamation program. From top to bottom: measuring twig length, leaf length, and plant height.

clipping all species at ground level within frames or by harvesting current annual growth.

Discussion:

If harvesting is used, choose a study area, place a circular loop on the area, and harvest within the loop. Or, estimate the weight of the plants within the circle, but harvest the species outside the plot (double-sampling procedure). The plants harvested can then be accurately measured and that figure can be applied back to the estimated values.

Perhaps the most commonly used method is simply to go to the revegetated site and harvest the plants for which you want production figures.

It is important to select harvest dates that correspond to collection of baseline data so that valid comparisons and evaluations can be made.

Certain measurements do not require harvesting, such as on-site measurements of morphological characteristics. Careful recordkeeping is essential.

UTILIZATION

With rare exceptions, a goal of reclamation is to put the land back into a form in which it can be utilized by livestock or wildlife. Thus, measuring utilization becomes another management task during the postmining phase.

How is utilization measured?

Techniques used to measure utilization include: (1) comparison of a grazed area with an ungrazed area and measuring the difference in plant standing crop, morphological characteristics, and shrub length, width, and height; (2) measurement of water intake by livestock, taking into account evaporation losses, the amount of moisture in the herbage and air temperature (this figure, coupled with dietary analysis, will enable the land manager to calculate utilization); or (3) review of the dietary preference list of wild animals in the area.

Discussion:

When comparing grazed to ungrazed areas:

• A portable cage can be placed over an area to be measured, and this can be moved throughout the grazing season after each harvest. When the cage is moved, harvest the herbage under th cage and harvest adjacent to the cage, the calculate the difference. This difference ind cates utilization.

• A permanent exclosure may also be use however, it is a less satisfactory indicator o utilization because the parameters inside an un grazed permanent exclosure are much differen from the areas that have been grazed.

REFERTILIZATION

As noted in the discussion of fertilization i chapter 6, mine spoils in the West are commonl deficient in nitrogen and phosphorous. Thu during the postmining monitoring period, it quite likely that a refertilization program w have to be established to ensure that the si receives sufficient nutrients to permanently e tablish vegetation.

How are refertilization needs identified?

Several methods can be used to determine re fertilization needs: soil tests, tissue tests, obser ing deficiency symptoms, greenhouse testin and field plots.

Discussion:

Soil tests are an important method identifying nutrient deficiencies, with the ex ception of nitrogen, which is best detected on-site observations or field plot studies. Tiss tests and greenhouse tests can supplement th methods. When using soil analysis, rely on qua fied suggestions of State testing labs or co mercial labs; follow recommended procedu for soil sampling. More information on observ deficiency symptoms can be found in chapter

How should the soil sample be taken?

Most experts outline the following s gestions:

1. Each sample should represent no m than 10 acres.

2. Ten to twenty samples are recommen depending on site variability.

3. Rooting depths of vegetation will gu how deeply one should sample.

4. Samples every 2-4 years are rec mended.

5. Sample when moisture conditions permit; given area should be sampled about the same onth each year to allow for nutrient variability uring the year.

6. Sample at a time so that fertilizer, if eeded, can be applied before the next growing ason—this means fall or early spring sampling.

hat amounts of nutrients are required?

This, of course, depends on the efficiency of e fertilizer, nutrient status of the spoil, and e deficiency in the plants.

iscussion:

Various guidebooks are available that will aid this determination. Results of soil tests and eld plots will also indicate the extent of re-rtilization required. The land manager should so be aware of the history of fertilization on e area, because rates of refertilization will de-end on what has been done in the past. (For ore specific information, refer to chapter 6.)

dditional Information:

For chemical analysis procedures, refer to Laboratory Methods Recommended for Chemi-l Analysis of Mined Land Spoils and Over-urden in the Western United States," by F. M. andoval and J. F. Power. USDA Handbook 25. 1977.

SPECIAL EMPHASIS AREAS

Some areas will need special attention during eclamation and postmining. These areas include losed roads, harsh sites, and those sites where ehabilitation failed.

low is road reclamation achieved?

For the most part, road beds can be success-ully revegetated using ripping, surface treat-nents, and hydromulch seeding techniques. In ome cases, however, successful maintenance nay mean road closure. The goal of road recla-nation is to control any erosion, siltation, or vater pollution caused by roads.

)iscussion:

Asphalt mixed with mulch and seed has been uccessful in binding the mulch and seed to the oad bed. Consult State highway departments for seeding formulas and other recommendations.

What types of harsh sites will require special attention?

Harsh sites that require special attention to achieve reclamation include southerly exposures in arid areas; subalpine, highly saline, or alkaline lands; and coarse-textured materials (fig. 51).

What is meant by special emphasis on reclamation failures?

Failures may result because of weather, rodents, insects, diseases, or bad management. This failed area must be given special attention during postmining and then must be monitored more carefully than successful sites.

Discussion:

It is important to note that some stands may take from 2-5 years to become established in arid and semi-arid areas. Often, plantings that were thought to be a failure at the end of the seeding year may develop into excellent stands because seeds may germinate 1 or 2 years after seeding if moisture was not available earlier. Thus, plantings should not be destroyed until they have been thoroughly examined.

MONITORING

Although the Surface Mining Control and Reclamation Act of 1977 (P.L. 95-87) applies only to coal, a statement relating to monitoring in Section 515.19 has general applicability when it states that the reclamation manager must "establish on the regraded areas and all other lands affected, a diverse, effective and permanent vegetative cover of the same seasonal variety native to the area of land to be affected and capable of self-regeneration and plant succession at least equal in extent of cover to the natural vegetation of the area; except that introduced species may be used in the revegetation process where desirable and necessary to achieve the postmining land use plan."

This effort must then be maintained for a required number of years after initial reclamation work is completed. Although another land use, such as for agriculture, or various State laws, may not make the above statement totally

Figure 51. Harsh sites, such as these bentonite spoils ponds, will require special reclamation emphasis and monitoring.

applicable, it does serve to emphasize that monitoring the reclaimed land will be an important function.

What is the role of the vegetation specialist in respect to monitoring?

The vegetation specialist should systematically monitor the revegetated mine site. Based on his input, the land manager will determine if the goals stated in the mining plan are being met.

Discussion:

Specifically, the vegetation specialist should consider the following:

- He should know what was stipulated in the mining plan; what are the agreed-upon goals of the reclamation effort. For example, in the mining plan the operator and land manager will have agreed when rehabilitation will be considered complete—when the land is revegetated, or when the land is being used by livestock or wildlife again.
- He should oversee augmented seeding, refertilization, irrigation, and any other work necessary to insure the establishment of permanent plant cover.
- He should set up a program to measure succession, productivity, and utilization on the site.
- Fundamental principles of rest-rotation grazing, deferred grazing, and grazing after seed maturity should be followed.
- Accurate recordkeeping of all these activities is necessary, especially if a question arises when the mining operator's bond of liability is to be released.
- The operator should be informed of the techniques the vegetation specialist will use to monitor the reclaimed site.
- If necessary, the vegetation specialist can recommend revisions in the postmining plan.

How long must the site be monitored?

Experience in end-use monitoring in the West is not sufficient at this time to state a number of years; however, some laws are setting such guidelines.

Discussion:

As one example, in the case of coal mined areas with less than 26 inches of annual precip

ion, the Surface Mining Control and Reclama-
n Act of 1977 states that, with certain ex-
ɔtions, the mining operator is responsible and
ɔle for the success of the reclamation effort
a period of 10 years after the last year of
gmented seeding, fertilization, irrigation, or
ıer work. Here, the vegetation specialist's role
a monitor would extend at least that many
ırs. In other cases, the time that elapses be-
e the operator is totally released from his
nd will depend on the stipulations of the min-
; plan. Even after the operator is released from
bond, however, the vegetation should be
ɔnitored by the land-management agency.

ıat are the main areas that are considered tical in postmining monitoring?

*The possible pollution of surface and sub-
face water and erosion are two of the major
as that must be closely monitored. Federal,
ıte, and local laws, however, may affect the*
ıte, and local laws, however, may affect the

scussion:

If a State requires succession of native ecies, the vegetation specialist will have to give special attention to determining if native species succession is occurring.

Additional Information:

Recommended texts on several of the subjects covered in this chapter include:

"Techniques for Vegetation Measurements and Analysis for a Pre and Post Mining Inventory," by C. Wayne Cook and Charles D. Bonham, Colorado State University, Range Science Dep., Science Series 28. August 1977.

"Methods for the Measurement of the Primary Production of Grassland," by C. Milner and R. Elfyn Hughes, International Biological Programme (IBP) Handbook No. 6. 1968.

"Range Research Methods," a symposium sponsored by the Division of Range and Wildlife Habitat Research, USDA For. Serv., May 1962. Miscellaneous Publication No. 940, U.S. Dep. of Agric.

"A Prediction Model to Estimate Revegetation Potentials of Land Surface Mined for Coal in the West," by Paul E. Packer, Chester E. Jensen, Edward L. Noble, and John A. Marshall. Proceedings of the International Congress on Energy and the Ecosystem, University of North Dakota, Grand Forks, N.D. June 1978.

APPENDIX A

GLOSSARY

idic soil: A soil that contains a preponderance hydrogen ions, often occurring when sulfide ierals are oxidized. Values below pH 7 indi- e an acidic soil.

apted species: Species that can complete their ire life cycles and replace themselves in suc- ding generations. Both introduced and native cies can be adapted species.

caline soil: Soil with a pH above 7 and which ntains excessive concentrations of soluble lts"—ions of calcium, magnesium, potassium, fate, chloride, nitrate, boron, and others. so see: sodic soil.)

re-root stock: Nursery stock grown 1-2 years beds, after which the individual plants are dug while dormant and are replanted.

seline data: Data gathered prior to mining for purpose of outlining conditions existing on undisturbed site. Reclamation success is asured against baseline data.

oadcast seeding: Randomly scattering seed on ground's surface. Aerial seeding and hydro- ding are types of broadcast seeding.

mpanion crop (synonymous with nurse crop cover crop): An annual crop, such as peas, ley, or oats, that is seeded with perennial cies to modify microenvironmental condi- ns during initial establishment.

ntainer-grown planting stock: Stock culti- ed in small containers and planted as dlings.

tical area: An area that should not be dis- bed (i.e., mined) because it is deemed ex- mely difficult or impossible to reclaim.

ttings: Sections of stems or branches, usually m woody plants, that are either cut from a nt and replanted at the site being revegetated, cut from the plant, rooted in a nursery, and nted as a transplant.

Drilling: A method of planting in which seeds are dropped into holes or furrows and covered with earth.

Electrical conductivity (EC): Electrical conductivity of a saturated extract used to measure soluble salts. A soil is considered saline if the EC of a saturated extract is 4 mmho/cm (U.S. Salinity Lab Staff).

Environmental Assessment (EA) (replaced the EAR): An analysis of all actions and their predictable short- and long-term environmental effects, which include physical, biological, economic, and social factors and their interactions. Also, a concise public document required by the regulations for implementing the procedural requirements of the National Environmental Policy Act of 1969 (NEPA).

Environmental Impact Statement (EIS): A document prepared by a Federal agency in which anticipated environmental effects of a planned course of action or development are evaluated, as described by the National Environmental Policy Act of 1969 (NEPA).

Exchangeable sodium percentage (ESP): The percentage of exchangeable sodium ions to other exchangeable cations in the soil. If this figure is 10 percent or higher, the soil may be sodic.

Feasibility study: As applied to mining, the feasibility study follows discovery of the mineral and is done by the mining company. Its purpose is to analyze the rate of return that can be expected from the mine at a certain rate of production. Based on this study, the decision to develop the ore body may be made.

Frost heaving: A condition that results from the flow of water through the soil to a freezing front where layers of ice are formed. This condition can thrust germinating seedlings out of the soil.

Hardening: Toughening of plants, especially container-grown stock, prior to planting by exposing the seedlings to colder temperatures and less

moisture. This enables the plants to make the transition from the controlled environment of a greenhouse to the harsher conditions of the mined site.

Hydromulching: Spraying mulch on the site with a stream of water.

Hydroseeding: Spraying seed on the site with a stream of water.

Inoculation: Treating seeds with appropriate host organisms, such as N-fixing bacteria, prior to planting.

Interdisciplinary team (ID team): As proposed by recent Forest Service regulations, the interdisciplinary team will be comprised of Forest Service personnel who collectively represent two or more areas of specialized technical knowledge about natural resources management applicable to the area being planned. The team will consider problems collectively, rather than separate concerns along disciplinary lines. This interaction will insure systematic, integrated considerations of physical, biological, economic, and other sciences.

Introduced species: A species that may be adapted to an area, but not native to it. An example would be alfalfa grown in the West.

Land-management plan: According to Forest Service regulations, each forest must have a forest plan, which outlines the most desired and alternative land uses for that site.

Mining plan: Submitted by the mining operator, the mining plan outlines the steps the mining company will take to mine and rehabilitate the site. The mining plan is submitted prior to start-up of mining operations.

Monitoring: In regard to disturbances caused by mining, the site must be carefully observed following reclamation operations to insure that reclamation goals are being met. This monitoring usually involves observations over time.

Mulch: Any nonliving material placed or left on or near the soil surface for the purpose of protecting it from erosion or protecting plants from heat, cold, or drought.

Native species: Plants that originated in the area in which they are found; i.e., they naturally occur in that area.

Nurse crop: See companion crop.

Overburden: Material overlying a minable deposit up to, but not including, the topsoil.

Oxidation of soil: The combination of substances in the soil with oxygen. If the substance is a sulfide, this oxidation may result in an acidic condition.

pH: Symbol for the negative common logarithm of the hydrogen-ion concentration (acidity) of a solution. The pH scale runs from 0 to 14. A pH of about 7 is considered neutral. A pH number below 7 is acidic and a pH value above 7 is alkaline or basic.

Plugs: Field-grown, native clumps of vegetation dug up and replanted in another site. Plugs may contain several plant species.

Preparatory crops: A crop seeded before perennial species; then the perennial species is seeded directly into the residue left from a preparatory crop without further seedbed preparation.

Primary species: Generally the first species to naturally invade a disturbed site. Primary species will colonize and initiate plant succession on the site.

Productivity: In reference to vegetation, productivity is the measure of live and dead accumulated plant materials. It is used to assess revegetation success.

Reclamation: Returning disturbed land to a form and productivity that will be ecologically balanced and in conformity with a predetermined land-management plan.

Rehabilitation: See reclamation.

Rhizomes: Underground stems of grasses, sedges, and other plants.

Saline soil: Soil containing sufficient salts to interfere with the growth of most crop plants

saline soil is indicated when the EC of a ırated extract is greater than 4 mmho/cm.

lic soil: A sodic soil occurs when exchange- e sodium ions are so concentrated in the soil t they may adversely affect plant growth. An ᴾ of 10 percent or higher, or an SAR of 10 or re, may indicate a sodic soil.

lium adsorption ratio (SAR): A lab measure- nt of the ratio of soluble sodium to soluble cium plus magnesium in soils. If the SAR is or more, the soil may be sodic.

l: The loose, uncemented minerals and anic material on the immediate surface of the th that serves as a natural medium for the wth of land plants; in this definition, soil y extends to the depth important for plant wth.

oils: The overburden (soil and raw geologic terials) removed in gaining access to the de- ed mineral deposit.

igs: Pieces of grasses and sedges that can be ted and replanted.

Succession: The process whereby one association of species replaces another, or the progressive changes in vegetation over time on an area.

Toxic soil: A soil containing concentrations of minerals so high as to be harmful to plants or animals.

Topsoil: The original or present dark-colored upper soil that ranges from a mere fraction of an inch to 2 or 3 feet thick on different kinds of soil. Most organic matter is concentrated in the topsoil.

Utilization: In reference to vegetation, utilization measures the amount of vegetation being used by animal species for forage in relation to the total amount of vegetation or given animal species available for grazing use.

Water harvesting: The practice of using the landscape to collect and accumulate water runoff and concentrate that moisture in a plant-growing zone.

Wildings: Individual plants transplanted from the wild to another site.

APPENDIX B

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APPENDIX C

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USDA Forest Service.
1979. User guide to vegetation. USDA For. Serv. Gen. Tech. Rep. INT-64, 85 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Summarizes and discusses key questions and rules the vegetation specialist should consider when working in mining area reclamation. Topics include land-management planning and baseline data; species selection; plant materials; site preparation; planting methods; cultural treatments; and postmining monitoring.

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THE SEAM PROGRAM

The Surface Environment and Mining Program, known as SEAM, was established by the Forest Service to research, develop, and apply new technology to help maintain a quality environment while helping meet the Nation's mineral requirements. SEAM is a partnership of researchers, land managers, mining industries, universities, and political jurisdictions at all levels.

Although the SEAM Program was assigned to the Intermountain Station, some of its research projects were administered by the Rocky Mountain and Pacific Southwest Research Stations.

MINERAL USER GUIDES

Other User Guides for specialists involved in minerals activities are:

- User Guide to Soils, Gen. Tech. Rep., INT-68
- User Guide to Engineering, Gen. Tech. Rep., INT-70
- User Guide to Sociology and Economics, Gen. Tech. Rep., INT-73
- User Guide to Hydrology, Gen. Tech. Rep., INT-74
- User Guide for Wildlife (planned)
- User Guide for Visual Management (to be published as part of the National Forest Landscape Management Series)

To obtain copies of these guides, write: Intermountain Forest and Range Experiment Station, USDA Forest Service, 507 25th St., Ogden, UT 84401.

ROLE OF FOREST FUELS IN THE BIOLOGY AND MANAGEMENT OF SOIL

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RESEARCH SUMMARY

Microbial activities are the principal biological determinants of forest site quality. The energy source or substrate for most microbes is derived from soil organic matter (fuels). Microbial activities most critical to site quality are nitrification, dinitrogen fixation, decay, ectomycorrhizal symbiosis, and pathogensis. Research on these subjects supports the following conclusions.

The end product of nitrification, nitrate, is subject to leaching loss. Nitrification is increased by forest disturbances, particularly clearcutting and burning. In most cases, losses of nitrogen are small and short lived.

The quantities of nitrogen fixed in forest soil by symbiotic associations are dependent on the presence of host plants. Such hosts are sometimes scarce. Nonsymbiotic nitrogen fixers depend only on organic matter. Soil humus, decaying and decayed wood, are important sites for nonsymbiotic nitrogen fixation, particularly during dry periods or on dry sites.

Soil humus and decayed wood are also the principal substrates for ectomycorrhizal symbionts during dry seasons and on dry sites.

Decay of wood and other organic material contributes to soil development by cycling carbon and minerals. Products of decay provide sites for nitrogen fixation and ectomycorrhizal activity. Decay of newly formed residues, to a point where they function in these capacities, is a long-term process.

Removing or burning forest fuels can lead to increased feeder root disease. It can also create wound entry sites for decay in living trees. In some instances this provides active centers of nitrogen fixation. Infected wood in root disease centers is a potential source for inoculation and further spread of the diseases.

Adequate quantities of woody residue, and other soil organic matter sources, are critical to optimal forest growth. Except where wood constitutes potential for disease or intense wildfire or where it is replaced in relatively short time spans (warm, moist sites) it should be conserved. This is particularly true of marginal (dry or cold) sites. Excess accumulation or inadequate supplies of wood provides an opportunity for site protection and enhancement through fuel management.

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INTRODUCTION

The quality of a forest site is governed by its physical conditions (temperature, moisture, soil parent materials) as they affect plant and soil. Microbes greatly affect soil development. Their activities mediate nutrient status through release, acquisition, retention, and recycling. Microbes, in part, are responsible for soil physical state, tilth, and water retention, by controlling type and quantity of organic materials. These factors, in turn, affect microbial plant symbionts and pathogens. Thus, microbial action in many types of organic fuels is a major biological determinant of site quality.

Interactions between forest uses and their residues (fuels) or lack of them bring about changes in both population size and types of soil microorganisms (Bell 1974). Most microbes are dependent on organic materials (plant bodies) either for their energy source or as a growing medium (substrate). Therefore, disruption of the quantity, type, and distribution of humus, litter, and wood imposes controls on their populations. The chemical-physical nature of organic matter also affects microbes. Water content, temperature, and reaction (pH) are all influenced by forest use, especially harvesting and burning (DeByle 1976; Bollen 1974).

EFFECTS OF FUEL DISTURBANCE ON SOIL BIOLOGICAL ACTIVITIES

Silvicultural activities and other forestry practices can influence type and quantity of forest fuels and hence have numerous effects on soil biology. Five biological effects are particularly significant:

(1) The conversion of other forms of nitrogen into nitrate (nitrification) and its potential loss by leaching.

(2) Fixation of atmospheric nitrogen.

(3) Decay of organic matter, with its effects on fuel reduction, mineral cycling, nitrogen acquistion, and organic structuring of the soil.

(4) Activities of mycorrhizal symbionts.

(5) Development of and damage caused by certain plant disease fungi (Harvey and others 1976a).

Knowledge accumulated on these subjects and results of current research in the northern Rocky Mountains suggests the following conclusions.

Nitrification

Nitrogen is usually the most limiting nutrient in forest ecosystems. Its quality and form in the soil is almost totally dependent on microbial action (Stone 1973). Consequently much interest is now developing with regard to the influence of forest uses on the ecology of the mocroorganisms that function in the cycling of nitrogen.

Decay or fire releases nitrogen from organic material in the form of ammonia. A select group of autotrophic soil bacteria, particularly *Nitrosomonas* and *Nitrobacter*, obtain their energy from a range of nitrogen compounds, especially ammonia. As a result of oxidation by these organisms, ammonia is converted to nitrate. Nitrate is not bound to soil exchange sites and creates a potential for leaching loss.

Clearcutting can dramatically increase this nitrification process (Rice and Pancholy 1972; Likens and others 1970). However, losses are usually small and short lived (Reinhart 1973).

Nitrogen Fixation

Another class of mircoorganisms of importance to the cycling of nitrogen are those that extract nitrogen from the atmosphere and convert it into forms useful to plants. There are two classes of nitrogen fixers:

(1) The symbiotic forms associated with plant nodules, usually the genus *Rhizobium*.

(2) A variety of nonsymbiotic nitrogen fixers that derive their energy from the breakdown of soil organic matter or from sunlight.

The relative contributions of symbiotic and nonsymbiotic forms to the nitrogen economy of forests is not well understood (Borman and others 1977; Wollum and Davey 1975; Jurgensen 1973; Jurgensen and Davey 1970). However, in many forest ecosystems, nodulated plants are infrequent. In contrast, nonsymbiotic nitrogen fixers are widely distributed, being found in nearly all forest soils.

The effects of fuel disturbance on symbiotic nitrogen fixers depends on the impact on distribution of the nodulated plants on which symbionts depend. Legumes and alder are examples of plants in the western United States that are favored by clearcutting (Youngberg and Wollum 1970). Opening forest stands also increase leguminous plants in the southeastern United States (Schultz 1976).

Nonsymbiotic nitrogen fixers are dependent on soil organic matter. Our data from western Montana show that humus and decayed wood are the principal sites for nonsymbiotic nitrogen-fixing activities. Smaller amounts are contributed by mineral soil and litter. Decaying woody materials, not yet incorporated into the soil, provide the highest-per-unit-weight nitrogen-fixing capacity of any material widely available on the forest floor (table 1).

Table 1.--Mean daily *nitrogen fixation rates from a Douglas-fir/larch stand* (ABLA/CLUN)[1] *in western Montana (June 24, 1976) based on five samples per stratum.*

Soil strata	Grams N_2/gram of dry substrate (10^{-9})[2]
Mineral soil	3.4
Humus (O_2)	18.8
Decayed wood in soil (O_3)[3]	29.0
Decaying log	142.0

[1]*Abies lasiocarpa/Clintonia uniflora* is a habitat type designation in western Montana (Pfister and others 1977).

[2]All fixatiors rates reported herin were determined by acetylene reduction (Hardy and others 1968).

[3]The O_3 horizon designation is used here to depict localized concentrations of brown cubicle decayed wood with mineral soil horizons that are clearly distinguishable from the litter layer (O_1 horizon) and humus layer (O_2 horizon).

Decay

The processes and organisms involved in decay of organic matter are essential to soil development through carbon and mineral cycling.

Past research has shown increased litter decomposition accompanies timber harvesting with attendant nutrient release and leaching from the soil (Packer and Williams 1976; Hart and DeByle 1975; Piene 1974; Cole and Gessel 1965). For most sites such losses are small. This was the result at our experimental site in western Montana.

The effect of harvesting on the decay of large fuels (logs) is presently uncertain; however, the end result of this process is known. Decaying logs are a significant site for nitrogen-fixing activity (Larsen and others 1978; Borman and others 1977; Cornaby and Waid 1973). The decayed residue, in the form of brown, crumbly wood on or in the soil provides a site for continued nitrogen fixation (table 1). Decayed wood becomes the primary site for this activity during dry periods or on dry sites (table 2). This is probably due to a unique ability of decayed wood to retain large quantities of moisture (table 3). It also has a much higher cation exchange capacity than other soil components, thus increasing soil cation exchange capacity. Decayed wood has been reported to make up 15-30 percent of the top 12-15 inches of various forest soils (Harvey and others 1976b; McFee and Stone 1966).

Table 2.--*Mean daily nitrogen fixation rates from various forest sites on July 24, 1976, (beginning of the summer dry period) based on three samples per stratum*

Site		Soil Strata		
		O_2[1]	O_3	M_1
		Grams N_2/gram of dry substrate (10^{-8})		
1 (PSME/PHMA)	warm-dry	5.9	22.8	2.3
2 (ABLA/CLUN)	cool-moist	15.8	32.3	3.2
3 (TSHE/CLUN)	warm-moist	39.5	30.6	2.1

[1]Soil strata are: O_2, humus; O_3, decayed wood in soil; M_1, first 5 cm mineral soil.

Table 3.--*Mean moisture content of soil strata from various forest sites, based on 150 random samples per site, June through September, 1976*

Site	Soil Strata	Moisture content (Pct. dry wt.)
1 (PSME/PHMA)	Litter (O_1)	58.6
warm-dry	Humus (O_2)	65.4
	Decayed wood in soil (O_3)	91.0
	Mineral (M_1)	17.1
2 (ABLA/CLUN)	O_1	110.3
cool-moist	O_2	116.8
	O_3	164.4
	M_1	34.0
3 (TSHE/CLUN)	O_1	122.6
warm-moist	O_2	117.3
	O_3	166.0
	M_1	27.0

Our preliminary estimates indicate that the input of functional decayed woody material into summer dry, winter cold forest soils characteristic of the northern Rocky Mountains may require hundreds of years.

Ectomycorrhizal Activity

The failure of afforestation efforts in areas lacking ectomycorrhizal associates for conifers attests to the obligate nature of the association between tree roots and fungi (Mikola 1973). Presence of the ectomycorrhizal association is particularly important to the ability to extract water, nitrogen, and phosphate from infertile soils (Bowen 1973; Melvin and Nilsson 1952).

Intense post-harvest burning is known to reduce mycorrhizal activity in subsequent regeneration (Wright and Tarrant 1958). This is probably a result of an alkaline shift in soil reaction, a high nutrient flux, and a reduction in soil organic matter. All these are detrimental to mycorrhizal development if they are extreme. The first two effects are transitory, the latter (decayed wood, etc.) is not.

In a mature ecosystem, upwards of 90 percent of the mycorrhizal activity in a stand is supported by organic matter (Harvey and others 1976b). During dry periods (Harvey and others 1978) or on dry sites most ectomycorrhizal activity is directly supported in decayed wood (table 4 and 5).

Table 4.--*Mean numbers of active mycorrhizal root tips per liter and moisture content of soil from a Douglas-fir larch (ABLA/CLUN)site in western Montana, by 60-day periods during the 1975 growing season*

Sampling period	Soil strata	Active tips/liter	Pct. H_2O
May-June	Litter (O_1)	5.9	112.0
	Humus (O_2)	369.0	130.1
	Decayed wood in soil (O_3)	75.4	204.7
	Mineral (M_1)	13.5	32.4
July-August	O_1	0	79.6
	O_2	75.4	74.2
	O_3	108.9	118.1
	M_1	4.6	27.9
September-October	O_1	4.0	156.6
	O_2	58.9	141.8
	O_3	27.9	244.4
	M_1	11.9	34.5

Table 5.--*Mean numbers of active mycorrhizal root tips per liter of soil from various forest sites, based on 150 random samples per site, June through October 1976*

Site	Soil strata	Active tips/liter
1 (PSME/PIMA) warm-dry	Litter (O_1)	0
	Humus (O_2)	12.8
	Decayed Wood (O_3)	17.2
	Mineral (M_1)	10.2
[illegible] cool-moist	O_1	1.6
	O_2	109.8
	O_3	25.2
	M_1	16.8
3 (TSHE/CLUN) warm-moist	O_1	82.7
	O_2	203.7
	O_3	108.4
	M_1	41.7

Thus, excessive residue removal could adversely impact some sites throughout one r more rotations, depending on the total amounts of woody material added to that site nd to its rate of decay and incorporation into the soil.

Disease Activity

Harvesting and burning can provide a major source of infection for many root and tem pathogens primarily due to wound damage in residual trees or changes in soil hemistry (Harvey and others 1976a).

Burning may increase the activities of the potentially damaging *Rhizina* root rot Morgan and Driver 1972) or other feeder root diseases of young conifers (Wright and ollen 1961). Thus far, in our lightly burned experimental plots, disease has made nly minor contributions to regeneration mortality.

In active root disease centers large, buried residues, stumps, and roots infected r subject to infection are known to perpetuate diseases (Nelson and Harvey 1974; aarik and Rennerfelt 1957; Gill and Andrews 1956).

The presence of root and stem disease should not, in all cases, be considered bad. e have discovered at least some types of pathological decay, as with residue (saprohytic) decay, provide a site for nitrogen fixation (table 6).

In overmature stands pathological decay contributes to preparation of the site for uture stands. This fiber loss can, therefore, be an energy investment in, as well as threat to future site productivity.

able 6.--*Daily nitrogen fixation rates from wood in live, standing western Hemlock and down, dead Douglas-fir. Decayed by* Echinodontium tinctorium *(Ell. & Ev.) and* Fomitopsis pinicola *(Swortz ex Ft.) Korst., respectively, based on 5 samples per decay type*

Decay stage	*E. tinctorium* (TSHE/CLUN)	*F. pinicola* (ABLA/CLUN)
	Grams N_2/gram of substrate (10^{-9})	
ndecayed (no visual discoloration)	20.7	17.1
ncipient decay (light dicoloration, wood firm)	22.2	15.8
dvanced decay (highly discolored, wood soft)	19.88	98.5

MANAGEMENT IMPLICATIONS AND RECOMMENDATIONS

Forest Fuels — An Asset

Forest managers and forest users should recognize the benefits, equivalent to long-term fertilization and moisture conservation, of retaining wood and other organic materials in forest ecosystems. Three separate lines of evidence (nitrogen fixation, decay rate, ectomycorrhizal activity) indicate these materials should be considered an important, functional part of forest soils, particularly on droughty sites.

Extreme scarification, intensive pile and burn, or hot wildfire that drastically reduces organic matter are potentially dangerous to dry sites. Such treatments may provide good early regeneration but poor ultimate survival and slow growth. This is primarily because both nitrogen and moisture reserves are lost from the root zone.

In extreme cases, because of slow decay rates on dry or cold sites, one or more rotations may be required to rebuild soil too low in organic matter to support the growth potential of that site.

Forest Fuels — A Liability

In specific areas, for example where fuel loading represents potential for highly destructive wildfire, or where woody residues are sources of pathogens from destructive disease centers, the benefits of removal will likely exceed those of preservation. Similarly, accumulations of organic matter in excess of site requirements may be undesirable. The potential for such circumstances is highest on cool, moist sites. This aspect of forest soil ecology is not, as yet, well documented.

High productivity and rapid decay render warm, moist forests less sensitive to long-term damage by depletion of soil organic matter either by fire or by other of man's activities.

Forest Fuels — An Opportunity

The vital role of wood in the functions of forest soil biology provides an opportunity for control of the soil system through harvest management. Where soils are low in organic matter, wood can be left on the site. Here it will gradually decay to provide nitrogen and moist microsites for ectomcorrhizal activity. Conversely, where wood has accumulated in quantity it can be removed and utilized or burned in place. Where the soil system is adequately supplied with organic matter it can be maintained in that condition. Thus, knowledgeable fuels management can improve, at least protect, any forest site where comtemplated use has the potential to disturb the distribution, quantity, or type of organic matter on that site.

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Reviews current understanding of and provides research data on the relationship between forest fuels (organic matter accumulations) and forest soil productivity. Concludes that soil organic matter and woody residues are important to ectomycorrhizal and nitrogen-fixing activities. Protecting site quality will likely become an important factor in residue management.

KEYWORDS: prescribed fire, wildfire, residues-fuel management, soil organic reserves, nitrogen fixation, ectomycorrhizal, disease, decay, nitrification.

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1979. Role of Forest Fuels in the Biology and Management of soil. USDA For. Serv. Gen. Tech. Rep. INT-65, 8 p. Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.

Reviews current understanding of and provides research data on the relationship between forest fuels (organic matter accumulations) and forest soil productivity. Concludes that soil organic matter and woody residues are important to ectomycorrhizal and nitrogen-fixing activities. Protecting site quality will likely become an important factor in residue management.

KEYWORDS: prescribed fire, wildfire, residues-fuel management, soil organic reserves, nitrogen fixation, ectomycorrhizal, disease, decay, nitrification.

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W. P. Handl, formerly Range Scientist with the Intermountain Station, participated in collecting field data, adapting computer programs, analyzing data, and developing the classification. Drs. G. A. Nielsen and L. C. Munn, Montana State University, supplied soil analyses. Research assistants participating in field sampling included Rick Miller, Rick Young, Mike McGinnis, Bob Yeager, and Wayne Leininger.

RESEARCH SUMMARY

A classification system is presented for the grasslands and shrublands of the mountainous western third of Montana. The classification utilizes the habitat type concept and is based upon potential natural vegetation. Data on plant species and environment from 580 relatively undisturbed stands were analyzed to form the classification. Twenty-nine habitat types occurring in 13 climax series are defined and described. A diagnostic key utilizing indicator plant species is provided for field identification of the habitat types.

Vegetation composition, distribution, and environment of each habitat type are described in the text. Tables are provided for detailed comparisons. Management related information on forage productivity, composition changes with grazing, and range management practices is summarized for each type.

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INTRODUCTION

The highly varied environment of the Northern Rocky Mountains creates a mosaic of forest, shrubland, and grassland vegetation. Species composition and productivity, and the consequent potential values, differ greatly between and within these major vegetation types. The ability to identify land units and relate them to both their inherent capability to produce various resources and their response to management activities is essential for multiple use planning and intensive resource management on our western wildlands.

The need to classify vegetation types and land units has long been recognized by natural resource managers. It is reflected by the development and use of numerous forest and range type classifications during the past fifty years. Unfortunately, such classifications have tended to stress current site occupancy and identity by a few commercially important plants. Little consideration has been given to the successional status of the existing vegetation or to the potential productivity of the environment as reflected by the "climax" vegetation.

In the past decade, the habitat type concept of environmental classification developed by Daubenmire (1952) has gained increasing acceptance in the West, particularly by forest managers. This concept stresses use of the entire climax plant community as an environmental integrator, thus permitting identification of environments (habitats) with similar biotic potentials. All environments with the potential to support approximately the same kind of stable (climax) mix of plant species are considered to be within the same habitat type regardless of current successional status. This approach to classification has been used successfully to classify both forest vegetation (Daubenmire and Daubenmire 1968; Pfister and others 1977) and grassland-shrubland vegetation (Daubenmire 1970) in the Northwest. This type of classification provides the framework essential for organizing information on resource potentials, limitations, and responses to management activities. Forests and rangelands of Montana, Idaho, and Washington are being mapped into site potential units (habitat types) so that information on each habitat type can be more widely applied.

Development of habitat type classifications for nonforested wildland has progressed more slowly than that for forested land. The need to develop such a classification for the nonforested lands of western Montana prompted a cooperative study between the Forest Service's Northern Region and Intermountain Forest and Range Experiment Station. The results of that study are reported here. The purpose of this study was three-fold: (1) to develop a habitat type classification scheme for the grasslands and shrublands of the mountainous western third of Montana (fig. 1); (2) to describe as well as is currently possible those characteristics of each habitat type that would be useful to the resource manager for developing management practices; and (3) to provide a framework for further management-oriented research.

Meeting the first objective required extensive sampling of relatively undisturbed grasslands and shrublands throughout western Montana and developing a classification based on similarities of the vegetation. The second objective was met by a combination of companion studies on vegetation productivity and soils, and by a synthesis of information found in a thorough review of publications and reports. This information was then related to the habitat types identified. The resulting classification identifies the basic land units to which future research can be tied, thus fulfilling the third objective.

Figure 1.--Physiographic division of Montana showing those portions of Northern Rocky Mountains pertinent to the study.

The nonforested land of western Montana was divided into 29 habitat types, which can be grouped into 13 climax series (table 1). This paper includes a key for identifying the types and a general description of each type. Supplemental information and technical data are given in the appendixes.

CONSIDERATIONS

The user of this guide to habitat types must bear in mind six considerations created by limitations in the study:

1. As discussed in the methods section (appendix A), development of a habitat-type classification should be based on data from a large number of areas of pristine vegetation. These conditions could only be partly met. Known areas of pristine vegetation were few, thus requiring inclusion of communities of varied and poorly documented grazing history. Grazing probably increases the variation in composition between stands which otherwise would be similar; this also increases the uncertainty of breaking out probable habitat types. Therefore, this classification is subject to changes as more information becomes available, especially for habitat types identified on the basis of relatively few stands.

2. Some of the western Montana habitat types are similar to those described by Daubenmire (1970) for the steppe region of eastern Washington. This similarity is somewhat superficial, for it is created primarily by the same dominant and codominant

species which are the basis for the habitat-type names. Comparison of all species suggests that the Montana types are distinct from those in Washington. A number of our species are associated with the Northern Great Plains flora which does not penetrate into eastern Washington. In like fashion, not all of the secondary species listed by Daubenmire occur in western Montana. Where duplication of our habitat-type names and those used by Daubenmire was unavoidable, a suffix of (Mont.) was added to the name to identify our habitat type as belonging to the Montana classification. This occurred once in the grassland series and five times in the shrubland series.

3. Certain species were taxonomically difficult to separate under the varied developmental stages encountered in the field. Among these were certain species of *Lupinus*, *Astragalus*, the more infrequent *Poa* spp. and certain rhizomatous *Agropyron* spp. The questionable taxonomic separation of *Festuca idahoensis* and *Festuca ovina* necessitated treating this complex as a single species, *Festuca idahoensis*. We are confident that most of our encounters were with *Festuca idahoensis*, but undoubtedly *Festuca ovina* was sometimes intermixed, particularly on subalpine sites. The possibly unfamiliar *Agrypyron caninum* species is used by Hitchcock and others (1955-69) for a group including the more familiar, but taxonomically uncertain, *Agropyron trachycaulum* and *Agropyron subsecundum*. We have adopted Hitchcock's usage to simplify field identification. Many of the early-drying ephemerals such as *Claytonia*, *Ranunculus*, *Dodecatheon*, and *Delphinum bicolor* are conspicuously absent from the species lists for the habitat types. These species were usually missed because most of our sampling occurred at midseason after they had dried and disintegrated.

4. In our attempts to identify changes in species composition that were attributable to grazing, we found that lack of consistency in species response was common. Certain species such as *Agropyron spicatum* and *Festuca scabrella* responded fairly consistently to grazing, but most species did not. The lack of consistency is probably attributable to a combination of such factors as the class and intensity of livestock use, the relative amount of the species available for grazing, and the stage of vegetation deterioration. We were unable to evaluate these factors separately. We placed a species into the response category of "decreaser" if most of the time it appeared to decline with grazing, and into the "increaser" category if it generally appeared to increase with grazing. Only exotic species that invaded and increased with abusive grazing or other disturbances were classified as "invaders." Many species were not classified because neither our data nor pertinent literature contained reasonably sound evidence of their response.

5. Several sources of error in interpreting impressions gained from visual comparisons of grazed and nongrazed areas and from actual data on canopy cover should be noted. Low mat-forming species, such as *Phlox hoodii*, may appear to increase substantially with grazing simply because they no longer are hidden by taller vegetation; canopy cover comparisons, however, often show no difference in actual amounts. On the other hand measuring canopy cover before and after grazing on the same area may show a decrease in a palatable species, which may not be real if the species is not adversely affected by partial removal of its canopy at the time of grazing. This possibility should be considered when comparing grazed area with adjacent exclosures. One must also remember that some species of relatively mediocre palatability may initially increase under abusive grazing only to decrease later when such abuse continues to the point where the more palatable plants no longer provide adequate forage.

6. The habitat types described in this report (table 1) and the key for their identification are specific to the mountainous western portion of Montana. The plains areas of the central and eastern part of the state were not included in our sampling. Applicability to adjoining mountainous areas in Wyoming, Idaho, and Canada has not been determined. The key in particular should be used with caution outside of the designated area. The key covers natural grassland and shrubland vegetation within the lower intermontane valleys and foothills on up through the subalpine type. The true alpine areas are not covered by this description.

Table 1.--Grassland and shrubland climax series, habitat types (h.t.), and phases in western Montana

Name	Abbreviation
STIPA COMATA CLIMAX SERIES	
Stipa comata/Bouteloua gracilis h.t.	*STCO/BOGR* h.t.
- *Agropyron smithii* phase	- *AGSM* phase
AGROPYRON SPICATUM CLIMAX SERIES	
Agropyron spicatum/Bouteloua gracilis h.t.	*AGSP/BOGR* h.t.
- *Liatris punctata* phase	- *LIPU* phase
Agropyron spicatum/Agropyron smithii h.t.	*AGSP/AGSM* h.t.
- *Stipa viridula* phase	- *STVI* phase
Agropyron spicatum/Poa sandbergii (Mont.) h.t.	*AGSP/POSA* h.t.
- *Stipa comata* phase	- *STCO* phase
FESTUCA SCABRELLA CLIMAX SERIES	
Festuca scabrella/Agropyron spicatum h.t.	*FESC/AGSP* h.t.
- *Stipa comata* phase	- *STCO* phase
Festuca scabrella/Festuca idahoensis h.t.	*FESC/FEID* h.t.
- *Geranium viscosissimum* phase	- *GEVI* phase
- *Stipa richardsonii* phase	- *STRI* phase
FESTUCA IDAHOENSIS CLIMAX SERIES	
Festuca idahoensis/Agropyron smithii h.t.	*FEID/AGSM* h.t.
Festuca idahoensis/Agropyron spicatum h.t.	*FEID/AGSP* h.t.
- *Stipa occidentalis* phase	- *STOC* phase
Festuca idahoensis/Agropyron caninum h.t.	*FEID/AGCA* phase
- *Geranium viscosissimum* phase	- *GEVI* phase
Festuca idahoensis/Carex filifolia h.t.	*FEID/CAFI* phase
Festuca idahoensis/Stipa richardsonii h.t.	*FEID/STRI* h.t.
Festuca idahoensis/Deschampsia caespitosa h.t.	*FEID/DECA* h.t.
DESCHAMPSIA CAESPITOSA CLIMAX SERIES	
Deschampsia caespitosa/Carex spp. h.t.	*DECA/CAREX* h.t.
ARTEMISIA ARBUSCULA CLIMAX SERIES	
Artemisia arbuscula/Agropyron spicatum h.t.	*ARAR/AGSP* h.t.
- *Stipa comata* h.t.	- *STCO* phase
Artemisia arbuscula/Festuca idahoensis h.t.	*ARAR/FEID* h.t.
ARTEMISIA TRIDENTATA CLIMAX SERIES	
Artemisia tridentata/Agropyron spicatum (Mont.) h.t.	*ARTR/AGSP* h.t.
Artemisia tridentata/Festuca scabrella h.t.	*ARTR/FESC* h.t.
Artemisia tridentata/Festuca idahoensis h.t.	*ARTR/FEID* h.t.
- *Geranium viscosissimum* phase	- *GEVI* phase
ARTEMISIA TRIPARTITA CLIMAX SERIES	
Artemisia tripartita/Festuca idahoensis (Mont.) h.t.	*ARTR/FEID* h.t.
POTENTILLA FRUTICOSA CLIMAX SERIES	
Potentilla fruticosa/Festuca scabrella h.t.	*POFR/FESC* h.t.
- *Danthonia intermedia* phase	- *DAIN* phase
Potentilla fruticosa/Festuca idahoensis h.t.	*POFR/FEID* h.t.
PURSHIA TRIDENTATA CLIMAX SERIES	
Purshia tridentata/Agropyron spicatum (Mont.) h.t.	*PUTR/AGSP* h.t.
Purshia tridentata/Festuca scabrella h.t.	*PUTR/FESC* h.t.
Purshia tridentata/Festuca idahoensis (Mont.) h.t.	*PUTR/FEID* h.t.
CERCOCARPUS LEDIFOLIUS CLIMAX SERIES	
Cercocarpus ledifolius/Agropyron spicatum h.t.	*CELE/AGSP* h.t.
RHUS TRILOBATA CLIMAX SERIES	
Rhus trilobata/Agropyron spicatum h.t.	*RHTR/AGSP* h.t.
Rhus trilobata/Festuca idahoensis h.t.	*RHTR/FEID* h.t.
SARCOBATUS VERMICULATUS CLIMAX SERIES	
Sarcobatus vermiculatus/Agropyron smithii h.t.	*SAVE/AGSM* h.t.
Sarcobatus vermiculatus/Elymus cinereus h.t.	*SAVE/ELCI* h.t.

IN WESTERN MONTANA.

(Instructions: This key applies specifically to nonforest vegetation *not severely altered* from pristine conditions--the user must allow for changes in community composition caused by abusive grazing, spraying, or other man-related disturbances. On severely altered sites, local remnants of relatively undisturbed conditions occurring on similar soils and landforms should be observed. Unavoidably, relative amounts of species are sometimes used as separation criteria. In most instances of questionable separation, the key will lead eventually to the same habitat type. Occasionally a community will be identified correctly even though one of the species constituting the habitat type or phase name is absent. This can happen because habitat types are determined by the entire floral composition and not just by the "name" species. When in doubt, check the general community composition with that shown for the respective habitat type in appendix E. The key is workable with a taxonomic knowledge of only 10 shrubs, 18 graminoids, and 6 forbs, most of which are common species readily identified by range technicians.)

1. *Festuca scabrella* conspicuous, usually with canopy cover exceeding 5% 2
1. *F. scabrella* absent or rare (less than about 1% canopy cover) 6
    2. Grassland aspect; shrubs, if present, are widely scattered or are such half-shrubs as *Artemisia frigida* and *Gutierrezia sarothrae*. (If *Potentilla fruticosa* present, go to 5) 3
    2. Woody plants common (generally over 5% canopy cover) and forming a shrubland aspect. 4

3. *Agropyron spicatum* common (at least 1 plant/4 ft^2); *A. frigida* and *G. sarothrae* usually conspicuous; *Geranium viscosissimum* and *Danthonia intermedia* absent. . . . . FESTUCA SCABRELLA/AGROPYRON SPICATUM h.t. (p. 23)
    a. *Stipa comata*, *S. spartea*, or *Boteloua gracilis* common (usually over 5% cover) . . . . STIPA COMATA phase
3. *A. spicatum*, if present, usually not common and not accompanied by either *A. frigida* or *G. sarothrae*; *G. viscosissimum* and/or *D. intermedia* often present and conspicuous . . . . FESTUCA SCABRELLA/FESTUCA IDAHOENSIS h.t. (p. 27)
    a. *Stipa richardsonii* present . . . . STIPA RICHARDSONII phase
    b. *S. richardsonii* absent; *G. viscosissimum* present . . . . GERANIUM VISCOSISSIMUM phase
    4. Shrubby aspect created by *Artemisia tridentata*; *Purshia tridentata* lacking . . . . ARTEMISA TRIDENTATA/FESTUCA SCABRELLA h.t. (p. 54)
    4. Shrubby aspect caused by species other than *A. tridentata* 5

5. *Purshia tridentata* dominant shrub . . . . .PURSHIA TRIDENTATA/FESTUCA SCABRELLA h.t. (p. 66)

5. *Potentilla fruticosa* common (over 5% cover), or as scattered plants often hidden by tall herbaceous growth . . . . .POTENTILLA FRUTICOSA/FESTUCA SCABRELLA h.t. (p. 60)

  a. *Danthonia intermedia* and *Agropyron caninum* present . . . . .DANTHONIA INTERMEDIA phase

6. *Festuca idahoensis* abundant, usually more than 5% canopy cover 7

6. *F. idahoensis* absent or rare (less than about 1% canopy cover) 21

7. Grassland aspect; shrubs, if present, are widely scattered or are such half shrubs as *Artemisia frigida* and *Gutierrezia sarothrae* 8

7. Woody plants common and generally forming a shrubland aspect. 16

8. *Agropyron spicatum* common (usually over 5% cover); perennial *Bromus* spp. absent or rare. . . . . . . .FESTUCA IDAHOENSIS/AGROPYRON SPICATUM h.t. (p. 32)

  a. *Stipa occidentalis* conspicuous and not exceeded in amount by *Stipa comata*. . . . . .STIPA OCCIDENTALIS phase

8. *A. spicatum* either absent or minor species with less canopy cover than other *Agropyron* spp.; may be conspicuous if perennial *Bromus* spp. prominent 9

9. *Artemisia frigida* present 10

9. *A. frigida* absent 11

10. *Agropyron smithii* and/or *A. dasystachyum* present . . . . .FESTUCA IDAHOENSIS/AGROPYRON SMITHII h.t. (p. 30)

10. *A. smithii* and *A. dasystachyum* absent . . . . .FESTUCA IDAHOENSIS/AGROPYRON SPICATUM h.t. (p.32)

  a. *Stipa occidentalis* conspicuous . . . . .STIPA OCCIDENTALIS phase

11. *Deschampsia caespitosa* present; *Phleum alpinum* and *Trisetum* spp. also often present; *Agropyron spicatum* absent. . . . . .FESTUCA IDAHOENSIS/DESCHAMPSIA CAESPITOSA h.t. (p. 44)

11. *D. caespitosa* absent 12

12. *Carex filifolia* present and both *Stipa occidentalis* and *Phlox hoodii* absent . . . . .FESTUCA IDAHOENSIS/CAREX FILIFOLIA h.t. (p. 41)

12. *C. filifolia* usually absent; if present, must be accompanied by *S. occidentalis* or *P. hoodii* 13

13. *Stipa richardsonii* abundant, usually exceeding 20% canopy cover . . . . .FESTUCA IDAHOENSIS/STIPA RICHARDSONII h.t. (p. 42)

13. *S. richardsonii* usually absent, but if present has less than 10% canopy cover 14

  14. *Geranium viscosissimum* and/or *Potentilla gracilis* present. . . . . .FESTUCA IDAHOENSIS/AGROPYRON CANINUM h.t. (p. 38)

    a. Both *G. viscosissimum* and *P. gracilis* present . . . . .GERANIMUM VISCOSISSIMUM phase

  14. Both *G. viscosissimum* and *P. gracilis* absent 15

15. *Agropyron smithii* and/or *A. dasystachyum* present . . . . .FESTUCA IDAHOENSIS/AGROPYRON SMITHII h.t. (p.30)

15. Both *A. smithii* and *A. dasystachyum* absent . . . . .FESTUCA IDAHOENSIS/AGROPYRON SPICATUM h.t. (p.32)

    a. *Stipa occidentalis* present . . . . .STIPA OCCIDENTALIS phase

  16. Shrubby aspect created by species of *Artemisia* 17

  16. Shrubby aspect created by shrubs other than *Artemisia*, which may be understory to taller shrubs 19

17. *Artemisia arbuscula* at least 5% canopy cover, even though *Artemisia tridentata* may be somewhat more abundant . . . . .ARTEMISIA ARBUSCULA/FESTUCA IDAHOENSIS h.t. (p. 49)

17. *A. arbuscula* absent or rare. 18

  18. *Artemisia tripartita* present and the dominant shrub; *Artemisia tridentata* may also be present. . . . . .ARTEMISIA TRIPARTITA/FESTUCA IDAHOENSIS h.t. (p. 58)

  18. *Artemisia tridentata* the dominant shrub . . . . .ARTEMISIA TRIDENTATA/FESTUCA IDAHOENSIS h.t. (p.55)

    a. *Geranium viscosissimum*, *Potentilla gracilis*, or *Potentilla glandulosa* and *Agropyron caninum* or *Bromus carinatus* present . . . . .GERANIUM VISCOSISSIMUM phase

19. *Purshia tridentata* abundant, usually dominant. . . . . .PURSHIA TRIDENTATA/FESTUCA IDAHOENSIS h.t. (p.67)

19. *P. tridentata* absent, or at least not a dominant shrub. 20

  20. *Potentilla fruticosa* common . . . . .POTENTILLA FRUTICOSA/FESTUCA IDAHOENSIS h.t. (p.62)

  20. *Rhus trilobata* common, or present in scattered patches on well-drained uplands or hillsides. . . . . .RHUS TRILOBATA/FESTUCA IDAHOENSIS h.t. (p.72)

21. *Agropyron spicatum* usually abundant; may have less than 10% canopy cover if *Bouteloua gracilis* has less than about 20% cover; woody plants may or may not be abundant. 22

21. *A. spicatum* absent, or at least less than about 2% canopy cover; woody plants other than half-shrubs rare 29

  22. Grassland aspect; shrubs, if present, are widely scattered or are such half-shrubs as *Artemisia frigida* and *Gutierrezia sarothrae*. 23

  22. Woody plants common and generally forming a shrubland aspect 25

23. *Bouteloua gracilis* usually more than 5% canopy cover; primarily east of Continental Divide . . . . .AGROPYRON SPICATUM/BOUTELOUA GRACILIS h.t. (p.14)

    a. Either *Liatris punctata* or *Carex filifolia* present. . . . . .LIATRIS PUNCTATA phase

23. *B. gracilis* absent or rare. 24

  24. Rhizomatous wheatgrasses and usually *Carex stenophylla* present; generally east of Continental Divide . . . . .AGROPYRON SPICATUM/AGROPYRON SMITHII h.t. (p.18)

    a. *Stipa viridula* and often *Vicia americana* present. . . . . .STIPA VIRIDULA phase

  24. Rhizomatous wheatgrasses absent; *Poa sandbergii* usually but not always present . . . . .AGROPYRON SPICATUM/POA SANDBERGII h.t. (p. 21)

    a. *Stipa comata* or *Stipa spartea* conspicuous. . . . . .STIPA COMATA phase

25. Shrubby aspect created by species of *Artemisia*. 26

25. Shrubby aspect created by shrubs other than *Artemisia*, which may be an associate. 27

  26. *Artemisia arbuscula* at least 5% canopy cover, even though *Artemisia tridentata* may be somewhat more abundant . . . . .ARTEMISIA ARBUSCULA/AGROPYRON SPICATUM h.t. (p.47)

    a. *Stipa comata* present; *A. tridentata* absent . . . . .STIPA COMATA phase

  26. *A. arbuscula* absent or rare; *A. tridentata* the dominant shrub .ARTEMISIA TRIDENTATA/AGROPYRON SPICATUM h.t. (p.50)

27. *Purshia tridentata* conspicuous, usually dominant. . . . . . .PURSHIA TRIDENTATA/AGROPYRON SPICATUM h.t. (p.64)

27. *P. tridentata* absent, or at least not a dominant shrub. 28

28. *Cercocarpus ledifolius* a dominant shrub. . . . . .CERCOCARPUS LEDIFOLIUS/AGROPYRON SPICATUM h.t. (p. 69)

28. *C. ledifolius* absent; *Rhus trilobata* abundant or present in scattered patches . . . . .RHUS TRILOBATA/AGROPYRON SPICATUM h.t. (p. 71)

29. *Sarobatus vermiculatus* abundant, creating a shrubland aspect (low elevation saline or alakline soils) 31

29. *S. vermiculatus* absent. 30

30. *Stipa comata* or *Bouteloua gracilis* dominant grasses (usually east of Continental Divide on dry alluvial benches and valley floors) . . . . . . .STIPA COMATA/BOUTELOUA GRACILIS h.t. (p. 10)

a. *Agropyron smithii* or *A. dasystachyum* conspicuous and *Carex filifolia* usually present. . . . . .AGROPYRON SMITHII phase

30. *S. comata* and *B. gracilis* absent; *Deschampsia caespitosa* and *Carex* spp. dominant graminoids (high elevation valley bottoms and flood meadows) . . . . .DESCHAMPSIA CAESPITOSA/CAREX spp. h.t. (p. 45)

31. *Elymus cinereus* a conspicuous associate . . . . .SARCOBATUS VERMICULATUS/ELYMUS CINEREUS h.t. (p. 74)

31. *E. cinereus* absent; *Agropyron smithii* dominating the herbaceous vegetation . . . . .SARCOBATUS VERMICULATUS/AGROPYRON SMITHII h.t. (p. 73)

TYPE DESCRIPTIONS AND MANAGEMENT IMPLICATIONS

Stipa comata /Bouteloua gracilis h.t.

(*STCO/BOGR* h.t.)

Distribution and environment.--The *STCO/BOGR* h.t. occurs primarily in the intermontane valleys east of the Continental Divide and south of 47° latitude. Usually it is confined to the broad alluvial benches, valley floors, or gently sloping alluvial fans extending into the valleys. Elevations of these sites are generally below 5,000 ft (1,500 m), but the type has been found as high as 6,100 ft (1,860 m) in the higher valleys of the extreme southwestern part of the State. This is the driest grassland habitat type in western Montana. Estimated precipitation is between 8 and 14 in (20 to 35 cm).

Soils from typical examples of the *STCO/BOGR* h.t. are of the fine-loamy Borollic Calciorthid subgroup, and are of aridic moisture and frigid temperature regimens (Munn, and others 1978). The solum is mildly alkaline with free calcium carbonate at or near the soil surface (appendix C3). The solum is approximately 20 in (50 cm) thick, with a 3 to 6 in (8 to 16 cm) A horizon (appendix C2). The amount of soil surface covered by rock ranges from 1 to 25 percent; bare soil ranges from 2 to 34 percent (appendix D).

Vegetative composition.--*STCO/BOGR* h.t. vegetation (fig. 2) is characterized by an abundance of *Stipa comata*, the constant presence of *Bouteloua gracilis*, and the rarity of *Agropyron spicatum* (appendix E1). At most, the latter species occurs only as widely scattered plants. The amount of *Bouteloua gracilis* depends upon past use; it usually increases greatly with overgrazing. *Artemisia frigida*, *Gutierrezia sarpthrae*, and *Opuntia polyacantha*, all low shrub life forms, usually are conspicuously present. The most constant though somewhat inconspicuous perennial forb is *Sphaeralcea coccinea*. This habitat type is floristically simple. Its plant cover consists primarily of grasses, with low cover values of forbs and shrubs (appendix D).

Figure 2.--*Stipa comata/Bouteloua gracilis* h.t. on a gently sloping alluvial fan near the valley floor at 5200 ft. elevation east of Twin Bridges in southwestern Montana.

The *Agropyron smithii* phase (*AGSM*) is a variant of this habitat type that contains richer and more productive flora with a greater proportion of forbs. The rhizomatous heatgrasses, *Agropyron smithii* and *Agropyron dasystachyum* are important components f its vegetation. *Carex filifolia* and *Koeleria cristata* are more constant and abundant, s are such forbs as *Chrysopsis villosa, Gaura coccinea, Liatris punctata,* and *Phlox oodii.*

Productivity.--Individual stands within the *STCO/BOGR* h.t. vary greatly in potenial productivity. Stands selected to span the range in production on good condition ites differed over threefold in peak biomass production. This great difference has ot been identified positively with specific site characteristics but is probably reated primarily to moisture. The more productive sites appear to fall within the *gropyron smithii* phase. Production also varies greatly from year to year because of eather. As much as a twofold difference in total biomass on a given stand was easured over a 3-year period. The extremes in production between stands in Montana nd a measure of variability between years are presented in table 2.

able 2.--*Extremes in production and variability over a 3-year period in the* Stipa comata/Bouteloua gracilis *habitat type*

	Stand 102		Stand 358	
	Average	SE[1]	Average	SE[1]
	Air-dry lb/acre[2]			
raminoids	235	59	699	89
orbs	5	5	107	46
hrubs	1	1	41	41
otal	241	57	847	128

[1]Standard error over 3-year period.
[2]Multiply by 1.12 for kg/ha.

Between 42 and 98 percent of the total biomass in three stands sampled for producivity consisted of grasses and sedges. Most of these graminoids (appendix E1) rank rom fair to good in palatability (appendix F) and can be considered potential forage. *tipa comata* and *Bouteloua gracilis* are generally the primary producers in this habitat ype. The former usually is considered the major forage species; its relative palataility depends upon associated species and declines with maturity. Although the canopy over of *Bouteloua gracilis* is often substantial, it does not provide much usable forge because of its low stature. *Agropyron smithii, Agropyron dasystachyum, Koeleria ristata,* and *Carex filifolia* may contribute substantially to forage production in the *gropyron smithii* phase of this habitat type. These species decline somewhat in palataility as the season progresses; however, fall regrowth is very palatable. Such poor r nonforage species as *Phlox hoodii* and *Opuntia polyacantha* seldom comprise a substanial portion of the total biomass unless the area is badly overgrazed.

Herbage yields reported in the literature from sites closely related to the *STCO/ BOGR* h.t. range from a low of 90 lb/acre (101 kg/ha) to a high of 2,400 lb/acre (2,690 g/ha). The low value was recorded in Canada during the 1930's (Smoliak 1956). The igher rates were recorded from stands in eastern Montana (Woolfolk 1949), western outh Dakota (Larson and Whitman 1942), and western North Dakota (Quinnild and Cosby 958).

The Canadian data are most applicable to the production potential of the *Stipa comata* series in western Montana. Smoliak (1956) reported that about 75 percent of the variation in yield can be attributed to yearly difference in May and June precipitation. Studies from Alberta (Smoliak 1960, 1965a, 1965b) and Saskatchewan (Campbell and others 1962) suggest that a range similar to this type in *excellent* condition may produce 480 lb/acre (538 kg/ha) of which 380 lb/acre (426 kg/ha) are graminoids. A similar range in *good* condition will produce only 320 lb/acre (358 kg/ha) of which 260 lb/acre (291 kg/ha) are graminoids.

Changes with grazing.--Heavy grazing in this habitat type, particularly by cattle and horses, inevitably results in a decrease in such palatable grasses as *Agropyron smithii*, *Agropyron dasystachyum*, and *Koeleria cristata*. Such unpalatable species as *Artemisia frigida*, *Gutierrezia sarothrae*, and *Opuntia polyacantha* are principal increasers. Smoliak (1974) found that although cover of *Bouteloua gracilis* does not change appreciably with light or moderate use, it increases on heavily grazed ranges. *Bouteloua gracilis* is a moderately palatable grass, but because of its low stature it can successfully withstand grazing pressure. We consider *Bouteloua gracilis* a principal increaser in this habitat type. The reaction of *Stipa comata*, the principal forage producer, to grazing depends upon season and intensity of use, and upon major associated species. It is less palatable than associated *Agropyrons* and its palatability declines with maturity. Although it is sometimes reported to be an increaser, our observations are that it generally decreases under heavy grazing in this habitat type. Smoliak (1965a) found that leaf length is a better indicator of *Stipa comata* vigor, and consequently reaction to grazing, than is basal cover.

Evidence accumulated by comparing differentially-grazed communities within the *Stipa comata* series and by surveying the published literature, suggests the following generalized categorization of species response to grazing in the *STCO/BOGR* h.t.:

Decreasers	Increasers	Invaders
Agropyron dasystachyum	*Antennaria dimorpha*	*Bromus tectorum*
Agropyron smithii	*Artemisia frigida*	*Melitotus officinalis*
Agropyron spicatum	*Bouteloua gracilis*	
Koeleria cristata	*Carex stenophylla*	
Oryzopsis hymenoides	*Calamagrostis montanensis*	
Stipa comata	*Chrysopsis villosa*	
Stipa viridula	*Erigeron compositus*	
	Gutierrezia sarothrae	
	Opuntia polyacantha	
	Poa sandbergii	
	Sphaeralcea coccinea	

Occasionally *Carex filifolia*, a fair forage sedge, and *Phlox hoodii*, a worthless forage species, are prominent in the type. Their response to grazing, however, appears too erratic to permit generalizations. In some cases these species appear to increase with grazing and in other instances to decrease.

Range management.--Cattle and horses are better able to utilize the *STCO/BOGR* h.t. than sheep because of the prevalence of grasses and lack of palatable forbs. Scarcity of water may limit livestock distribution and, on large areas, result in uneven utilization of forage. The type is most often utilized in early spring before forage becomes available at the higher elevations, and again in late fall and winter after the grasses have cured. The sharp achenes and long, twisted awns of *Stipa comata* may cause mechanical injury to livestock if grazed after the flower stalks have developed and before the seeds have shattered. Pronghorn antelope may use this type year-long; mule deer may use it somewhat during the winter.

Proposed proper use values for the major grasses differ according to class of livestock; they also differ somewhat by season of use, plant species, and investigators. Reed and Peterson (1961) suggest the following conservative values, expressed as a percentage of total annual growth, for season-long grazing by cattle:

Agropyron smithii	30%
Bouteloua gracilis	25%
Stipa comata	25%

Proper use values recommended by Woolfolk (1949) for season-long sheep grazing and by Holscher and Woolfolk (1953) for cattle winter use are considerably higher:

	Season-long		Winter
	Sheep	Cattle	Cattle
Agropyron smithii	20%	55%	65%
Bouteloua gracilis	30%	45%	40%
Stipa comata	20%	60%	60%
Carex filifolia	20%	50%	50%

Woolfolk (1949) indicated that average stubble heights at termination of season-long grazing by sheep should be:

Agropyron smithii	2.5 in (6.4 cm)
Bouteloua gracilis	0.5 in (1.3 cm)
Carex filifolia	1.0 in (2.5 cm)

Campbell and others (1962) recommended that 20 percent of all seed stalks should remain following grazing of this general type of vegetation.

Upon comparing grazing systems on Great Plains vegetation similar to our *Stipa comata* series, Rogler (1951) found that rotation grazing is not superior to continuous grazing for maintaining good condition range. Furthermore, he found continuous grazing resulted in greater gains of yearlings or 2-year-old steers than did rotation grazing. He concluded that although rotation grazing may benefit overgrazed range of this type, complete deferment until recuperation would lead to more rapid and satisfactory improvement. Hubbard (1951), working in Alberta, also found that although deferred rotation grazing may improve depleted ranges of this type, it does not benefit ranges already in good condition. He concluded that conservative continuous grazing is the most practical management. Prolonged heavy sheep grazing in this type can cause forage deterioration by permitting an increase in *Bouteloua gracilis* and decrease in the more productive *Agropyron smithii* and *Stipa comata*. For Alberta conditions, Smoliak (1974) recommended that sheep stocking rates under a continuous grazing system not exceed one sheep-month per acre. Possibly a rest-rotation grazing system tailored to specific conditions may permit efficient use of this habitat type.

Overall productivity of this type of range can be increased by nitrogen fertilization. In the Northern Great Plains, applying 30 to 50 lb/acre (34 to 56 kg/ha) of N commonly doubled total herbage production (Wight 1976). However, such an increase in total herbage biomass does not necessarily mean an equivalent increase in production of palatable forage. Such poor to fair forage species as *Phlox hoodii*, *Artemisia frigida*, and *Taraxicum officinale* may provide the bulk of the increase (Klages and Ryerson 1965). The rhizomatous wheatgrasses usually respond more favorably to fertilization than the less desirable *Bouteloua gracilis* (Smoliak 1965b; Lorenz and Rogler 1972). Effects of the fertilizers can carry over into subsequent years in this relatively dry type. Smoliak (1965b) noted significant increases in production 8 years following fertilization

on the Northern Great Plains. When fertilization is accompanied by spraying with 2,4-D to control forbs, a significant increase in grass forage usually can be expected (Smika and others 1965). Although range pitting and interseeding may increase forage production, it does not appear to be economical in this type (Wight and White 1974).

Strategically located water developments and placement of salt can markedly enhance uniform use of the large expanses of range commonly occupied by this habitat type.

Noted elsewhere.--Ross and others (1973) described several stands of vegetation in eastern Montana that appear similar in composition to the *STCO/BOGR* h.t. Coupland (1961) described a *Stipa-Bouteloua* faciation of the mixed prairie in southern Saskatchewan and Alberta that is also very similar to our western Montana *STCO/BOGR* h.t. Coupland's faciation was limited to sandy soils on dry sites. The main species difference appears to be the occurrence of *Artemisia cana* in the Canadian vegetation.

What appears to be an environmental counterpart in eastern Washington was identified by Daubenmire (1970) as the *Stipa comata/Poa sandbergii* h.t. His type, however, lacks certain major species associated primarily with the flora of the Great Plains. Important species in the *STCO/BOGR* h.t. not occurring in the eastern Washington type are *Bouteloua gracilis*, *artemisia frigida*, *Carex stenophylla*, *Gurierrezia sarothrae*, and *Sphaeralcea coccinea*.

Agropyron spicatum/Bouteloua gracilis h.t.

(*AGSP/BOGR* h.t.)

Distribution and environment.--The *AGSP/BOGR* h.t. is found east of the Continental Divide on toeslopes of the foothills and steeper slopes off the valley bottoms. The lower edge of the type commonly abuts the *STCO/BOGR* h.t. The *STCO/BOGR* h.t. occurs primarily on the more southerly exposures on slopes up to 35 percent and at elevations usually less than 6,000 ft (1,800 m). This habitat type is somewhat less arid than the *STCO/BOGR* h.t.; estimated precipitation ranges from about 12 in to as high as 18 in (30 to 46 cm), but potential evapotranspiration is high.

Soils from representative examples of the *AGSP/BOGR* h.t. are Typic Argiborolls and Entic Haploborolls. They are of both ustic and aridic moisture and of frigid temperature regimens (Munn and others 1978). The type occurs on a great diversity of parent materials. Thickness of the soil solum varies greatly, with a 4 to 7 in (10 to 18 cm) A horizon (appendix C2). The solum is neutral in reaction (pH 7.1), with free calcium carbonates generally restricted to depths greater than 6 in (15 cm). The soils appear relatively nitrogen-poor and have a high C:N ratio compared to other habitat types (appendix C3). The amount of surface rock varies appreciably, from 1 to 46 percent; bare soil varies from 1 to 42 percent (appendix D).

Vegetative composition.--*Agropyron spicatum* shares dominance with *Stipa comata* (fig. 3). As in the *STCO/BOGR* h.t., *Bouteloua gracilis* is always present, but in varying amounts depending upon grazing history. Generally, it is a conspicuous and important part of the flora with a potential to increase substantially under heavy grazing. Usually *Koeleria cristata*, *Poa sandbergii*, and *Carex stenophylla* are also present. *Phlox hoodii* and *Sphaeralcea coccinea* are the most constant forbs. *Artemisia frigida* is always present and conspicuous; *Gutierrezia sarothrae* and *Opuntia polyacantha*, also low-growing shrubs, are usually present (appendix E2). The *AGSP/BOGR* h.t. may contain several species of medium-tall shrubs, but they are seldom abundant. The most constant of these shrubs is *Chrysothamnus nauseosus*. Grasses form by far the greatest part of the total vegetation cover (appendix D). Forbs and shrubs, however, are somewhat more abundant than in the *STCO/BOGR* h.t.

The richer flora occuring within the *Liatris punctata* phase (*Lipun*) of the *AGSP/BOGR* h.t. probably reflects a slightly more productive site. This phase is characterized by the presence of either *Liatris punctata*, or *Carex filifolia* and *Calamagrostis montanensis*. The conspicuous forb *Chrysopsis villosa* is also more consistently present.

Figure 3.--*Agropyron spicatum/Bouteloua gracilis* h.t. on a gentle west-facing slope, 5,000 ft, elevation, in the foothills west of Bozeman in southwestern Montana.

Productivity.--Although overall productivity of this type does not differ greatly from that of the *STCO/BOGR* h.t., the vegetation is composed of more desirable forage. Individual stands within the *AGSP/BOGR* h.t. can differ considerably in productivity because of both site conditions and yearly weather differences. Stands purposefully selected in western Montana to span the range in site-induced differences in productivity indicate that the better sites are capable of producing twice as much as the poorer sites. Site potential within the habitat type appears related to soil depth and consequently soil moisture storage capacity. Weather variations over a 3-year period caused as much as 180 percent difference in herbage production. The extremes in productivity between stands in the *AGSP/BOGR* h.t., and a measure of variability attributable to weather differences between years are presented in table 3.

Table 3.--*Extremes in production and variability over a 3-year period in the* Agropyron spicatum/Bouteloua gracilis *habitat type*

	Stand 9		Stand 179	
Growth form	Average	SE[1]	Average	SE[1]
	- - - - - - - - -	-*Air-dry lb/acre*[2]-	- - - - - - - - -	
Graminoids	243	24	467	47
Forbs	117	15	310	102
Shrubs	71	37	63	44
Total	431	47	773	127

[1]Standard error over 3-year period.
[2]Multiply by 1.12 for kg/ha.

At least half (50 to 60 percent) of this total biomass consists of graminoids which are rated fair to good in palatability (appendixes E2, F). *Agropyron spicatum* and *Stipa comata* are the primary forage producers. *Koeleria cristata, Poa sandbergii,* and *Carex* spp. may contribute substantially to forage production. Although *Bouteloua gracilis* is usually conspicuous in the type, it produces little usable forage because of its low stature.

Forbs as a group can constitute approximately 30 percent of the total biomass. No single species, however, is noted as a major producer of palatable forage. The more abundant forbs, such as *Phlox hoodii,* and *Chrysopsis villosa* are often poor forage species. The most consistent and abundant shrub, *Artemisia frigida,* is considered, at best, only fairly palatable.

Changes with grazing.--Many others (Daubenmire 1940; Ellison 1960; McLean and Marchand 1968) concluded as we have that *Agropyron spicatum* is a major forage species that declines with excessive grazing in the *Agropyron spicatum* series. Mueggler (1972a) found that a decrease in flower stalk numbers is a more sensitive indicator of vigor decline in this grass than either herbage production or leaf and flower stalk lengths. Principal species that increase with overgrazing are *Artemisia frigida, Bouteloua gracilis,* and *Gutierrezia sarothrae.* Usually *Stipa comata* will tend to increase with the decline of *Agropyron spicatum.* If overgrazing persists, *Stipa comata* too will decline. *Artemisia tridentata* and *Chrysothamnus* spp., normally incidental shrubs on good condition range of this type, may increase to a level of dominance under extreme abuse.

The following list of species and their response to overgrazing in the *Agropyron spicatum* series was developed from our comparisons of differentially grazed stands and from reviewing appropriate literature:

Decreasers	Increasers	Invaders
Agropyron spicatum	*Antennaria dimorpha*	*Bromus japonicus*
Liatris punctata	*Artemisia frigida*	*Bromus tectorum*
Lygodesmia juncea	*Artemisia tridentata*	*Centaurea maculosa*
Oxytropis riparia	*Bouteloua gracilis*	*Cirsium vulgare*
Potentilla pennsylvanica	*Carex stenophylla*	*Taraxicum officinale*
Stipa viridula	*Chrysopsis villosa*	*Tragopogon dubius*
	Chrysothamnus nauseosus	
	Chrysothamnus viscidiflorus	
	Erigeron filifolius	
	Galium boreale	
	Grindelia squarrosa	
	Gutierrezia sarothrae	
	Helictotrichon hookeri	
	Hymenoxys acaulis	
	Lesquerella alpina	
	Lupinus sericeus	
	Paronychia sessilifolia	
	Poa sandbergii	
	Sphaeralcea coccinea	
	Sporobolus cryptandrus	

Although we have stated that *Artemisia frigida* and *Bouteloua gracilis* are principal "increasers," they do not always behave this way. In our paired-stand grazing comparisons (appendix G2), canopy cover of *Artemisia frigida* is significantly greater in stand 194, which is inside of an exclosure and has been protected from grazing for about 10 years, than in stand 195 which is outside and is grazed by cattle. Both areas appear to have been heavily grazed by sheep in the past. Canopy cover of *Bouteloua gracilis* is significantly greater in stand 13, moderately grazed by cattle and horses, than in the immediately adjacent stand 12, which is heavily grazed by cattle and horses. These two stands also were probably grazed heavily by sheep prior to about 1950. More typically, however, overgrazing enhances the enlargement of mats of *Bouteloua gracilis,* and greatly increases the numbers of *Gutierrezia sarothrae* and *Artemisia frigida.*

Agropyron smithii, Agropyron dasystachyum, Koeleria cristata, Stipa comata, and *Phlox hoodii* are often prominent species in the *Agropyron* series. However, we have not been able to generalize on their response to grazing because of extreme inconsistency.

Range management.--The *AGSP/BOGR* h.t. is more suitable for use by cattle and horses than it is for sheep. Palatable grasses are usually abundant, but palatable forbs are relatively scarce. A greater amount of forbs enhances the value of the *Liatris punctata* phase as sheep range. Lack of adequate stock water may limit use during the summer and early fall periods. The awns of *Stipa comata,* which is usually abundant in this type, may cause mechanical injury to livestock if grazed in late spring and early summer. Consequently this low elevation type is best suited for spring and late fall grazing. Use during early summer should be intermittent and moderate. Primary big game use is by pronghorn antelope and as winter range for mule deer. The type is also used somewhat by elk during winter.

Management of this habitat type should be directed specifically at *Agropyron spicatum.* It is the major forage producer and is also sensitive to abusive grazing. The most crucial period of use for this grass appears to be after the date when substantial regrowth is impossible yet before the plant matures, or about the flowering growth stage (Blaisdell and Pechanec 1949). At this time carbohydrate reserves in the roots are low and the plant is usually unable to produce regrowth because soil moisture is limiting. Heavy utilization and lack of regrowth leaves the plant without the means for producing carbohydrates to build up the root reserves. Wilson and others (1966a) found that *Agropyron spicatum* was most sensitive to clipping when in the boot stage of floral development.

Average stubble height of grasses at the end of the grazing season is often used as an indicator of proper use. Heady (1950) found that *Agropyron spicatum* clipped to a 6-in (15-cm) stubble height or less at the time of flowering suffered vigor losses the following year. A 6-in stubble height represented 40 to 60 percent weight removal, depending upon original height of the plant. Mueggler (1972a) found that a 50 percent weight removal just before full emergence of inflorescence caused a 50 percent reduction in total weight and 95 percent reduction in flower stalk numbers the following growing season. When competition from surrounding vegetation was reduced by clipping, the vigor loss in *Agropyron spicatum* was neither as immediate nor as great but was still substantial. Obviously, less than 50 percent, perhaps no more than 30 percent, of current growth should be utilized if this species is grazed during the peak of growth. McLean and Marchand (1968) indicate that grazing *Agropyron spicatum* in the spring should not occur until the grass is at least 4 in (10 cm) high. They state that root reserves of this grass are minimal when the tops are 7 in (18 cm) high. Consequently, early spring grazing must be terminated in time to permit additional growth and storage of food reserves in the roots. Utilization may be as much as 50 or 60 percent, or even greater, if grazed after *Agropyron spicatum* has cured in late summer or fall. McIlvanie (1942) found that maximum amounts of carbohydrates were stored as root reserves about 2 months after appearance of the flower stalks. Late season grazing, therefore, should not seriously harm the potential for overwintering and growth initiation the following year. If an *Agropyron spicatum*-dominated range is in poor condition, grazing should be deferred until fall or early winter to permit the plants to regain vigor.

Various studies have shown that the number of flower stalks is a sensitive indicator of vigor in *Agropyron spicatum* (Blaisdell and Pechanec 1949; Mueggler 1972a). However, further studies (Mueggler 1975) revealed that maximum lengths of flower stalks may actually be a more reliable indicator of initial vigor loss than numbers of flower stalks. Evaluation of vigor requires comparison with protected (ungrazed) plants of normal vigor because both numbers and lengths of flower stalks vary greatly between years because of weather. Once the vigor of *Agropyron spicatum* is lowered, recovery can be very slow. Mueggler (1975) concluded that moderately low vigor *Agropyron spicatum* in a *FEID/AGSP* h.t. may require at least 6 years of protection to recover fully; complete recovery of very low vigor plants can take more than 8 years of protection.

Fertilization may increase overall production within the *AGSP/BOGR* h.t., but this practice is of questionable economic value. Unpalatable forbs tend to respond as readily as the grasses to nitrogen fertilization. Consequently, full benefit of fertilization for improved forage production on native vegetation usually can be obtained only if accompanied by herbicide treatment to control the unwanted forbs and shrubs. Fertilization of ranges in the *Agropyron spicatum* series that contain *Bromus tectorum* as a component of the vegetation could result in a substantial decrease in *Agropyron spicatum*. Wilson and others (1966b) found that applying nitrogen at the rate of 80 lb/acre (90 kg/ha) for 4 consecutive years resulted in a 50 percent reduction in yield of *Agropyron spicatum* and a 400 to 600 percent increase in *Bromus tectorum*.

Noted elsewhere.--At least 11 stands of near pristine vegetation described by Ross and others (1973) for the sedimentary plains and foothill areas throughout Montana have the same species composition as the *AGSP/BOGR* h.t. All of these stands are within the 10- to 14-in (25-to 35-cm) precipitation zone, and occur primarily on relatively shallow, sandy-loam soils.

Agropyron spicatum /Agropyron smithii h.t.

(*AGSP/AGSM* h.t.)

Distribution and environment.--This habitat type occurs most frequently east of and only occasionally west of the Continental Divide. Generally it is found at elevations between 4,000 and 5,700 ft (1,200 and 1,700 m), and on all exposures. Although it can occur on slopes as steep as 40 percent, most of the time it will be found on slopes less than 20 percent. The *Stipa viridula* phase (*STVI*) is associated with the slightly steeper slopes. The *AGSP/AGSM* h.t. is moderately arid, usually occurring within the 12- to 18-in (30- to 46-cm) precipitation zone.

Soils were analyzed in detail from two typical examples of the type. Both are Entic Haploborolls; one is of an ustic and the other an aridic moisture regimen; both are of a frigid temperature regimen (Munn and others 1978). Solum thickness of the two soils averages 11 in (28 cm) with a 9-in (22-cm) A horizon. Solum pH is neutral, with free calcium carbonate not reached until 7 in (18 cm). Surface rock cover of 16 stands sampled in this type ranges widely from 1 to 70 percent; bare soil ranges from 1 to 32 percent (appendix D). The type does not appear restricted to any particular soil parent materials.

Vegetative composition.--A definite grassland aspect, the dominance of *Agropyron* [illegible], the abundance of rhizomatous wheatgrasses (*Agropyron smithii* and/or *Agropyron dasystachyum*), and the lack of *Bouteloua gracilis* characterize the *AGSP/AGSM* h.t. (fig 4). If present, *Bouteloua gracilis* is usually inconspicuous and unable to increase substantially with overgrazing. Other important grasses include *Koeleria cristata*, *Stipa comata*, and either *Poa sandbergii* or *Poa cusickii*. The low shrubs *Artemisia frigida* and *Gutierrezia sarothrae* are usually present and may be abundant.

Figure 4.--*Agropyron spicatum/Agropyron smithii* h.t. on a gentle southwesterly slope at 5,100 ft. elevation where the plains meet the mountains near Judith Gap in Central Montana.

Medium tall shrubs are not prominent. Forbs are generally much more diverse and important here than in the *AGSP/BOGR* h.t. *Chrysopsis villosa, Phlox hoodii, Spaeralcia coccinea,* and *Tragopogan dubius* are the most constant and conspicuous forbs (appendix E2).

The *Stipa viridula* phase is characterized by the presence and often abundance of this grass. *Vicia americana* is a prominent forb usually confined to this phase.

Productivity.--Judging from the stands selected to span the range in forage potential within this habitat type, productivity varies more between years than between stands. Differences in total biomass between stands averaged about 20 percent over a 3-year period. Differences between years attributable to weather amounted to 54 percent in one stand and 67 percent in another. Typical productivity values for extreme stands are presented in table 4.

Table 4.--*Extremes in production and variability over a 3-year period in the* Agropyron spicatum/Agropyron smithii *habitat type*

	Stand 83		Stand 248	
Growth Form	Average	SE[1]	Average	SE[1]
	Air-dry lb/acre[2]			
Graminoids	488	64	742	107
Forbs	191	54	60	21
Shrubs	2	2	1	1
Total	680	94	803	116

[1]Standard error over 3-year period.
[2]Multiply by 1.12 for kg/ha.

More than two-thirds of the total biomass consists of grasses and sedges. *Agropyron spicatum* is the major forage producer. Other important forage species include *Stipa comata*, *Agropyron smithii*, *Agropyron dasystachyum*, *Koeleria cristata*, and *Poa cusickii* (appendixes E2, F). *Stipa viridula* generally produces a substantial amount of forage in the *Stipa viridula* phase of this habitat type.

Although numerous species of forbs may be present, they do not contribute very much to forage production. They usually are neither abundant nor palatable. *Vicia americana* is an exception; it can be a productive forage species in the *Stipa viridula* phase. *Artemisia frigida* is often abundant, but is only fairly palatable.

Changes with grazing.--Expected reactions of plant species to abusive grazing within the *Agropyron spicatum* series are covered in the *AGSP/BOGR* h.t. description. Generally, *Agropyron spicatum* and *Stipa viridula* are the principal decreasers within the *AGSP/AGSM* h.t. *Agropyron smithii* and *Agropyron dasystachyum*, two rhizomatous wheatgrasses, and *Stipa comata* usually increase as *Agropyron spicatum* decreases; however, they too will decrease with continued heavy grazing. *Artemisia frigida*, *Gutierrezia sarothrae*, and *Chrysopsis villosa* are the principal species that increase with overgrazing. Seemingly, *Phlox hoodii* should increase also because of its low matted growth form and lack of palatability, but it responds erratically. We can expect a substantial increase in *Opuntia polyacantha*, *Artemisia tridentata*, and *Chrysothamnus* spp. in this type if overgrazing persists.

Range management.--Considerations in managing this habitat type are similar in many ways to those discussed for the *AGSP/BOGR* h.t. *Agropyron spicatum* is a primary forage producer and the environmental situations do not differ greatly. Both types are best suited as cattle range. The major difference that concerns management of these two types is the abundance of the rhizomatous *Agropyron smithii* and/or *Agropyron dasystachyum* and the relative scarcity of the mat-forming *Bouteloua gracilis* in the *AGSP/AGSM* h.t. These rhizomatous wheatgrasses are better able to withstand heavy grazing than *Agropyron spicatum*. If *Agropyron spicatum* declines, the rhizomatous wheatgrasses usually increase. Thus forage production tends to be maintained. However, if abusive grazing continues, the rhizomatous wheatgrasses also will suffer, as will total forage production. Everson (1966) suggests that utilization of *Agropyron smithii* should not exceed a 4-in (10-cm) stubble height to maintain good vigor. In one case, moderate continuous grazing over a 34-year period did not appreciably harm *Agropyron smithii* (Rogler 1951). Buwai and Trlica (1977), however, propose a rest-rotation grazing system for such semiarid ranges to insure that grazed plants such as *Agropyron smithii* receive rest following grazing during critical growth periods.

Fertilization, mechanical treatment, and waterspreading may be ways of improving forage production in this habitat type under the proper circumstances. Goetz (1970) found that the vigor of *Agropyron smithii* can be increased by application of 67 lb/acre (75 kg/ha) nitrogen. In eastern Montana on *Agropyron smithii*- and *Bouteloua gracilis*-dominated sites, Houston (1960) found that waterspreading is economically feasible, given the right combination of topography and access to a supplemental source of water. He determined that flooded sites produced 62 percent more herbage and ponded sites 189 percent more herbage than areas where supplemental water was not added. Species composition did not change on sites dominated by *Agropyron smithii*. In Houston's study, the annual gross returns per acre were approximately seven times the annual per acre cost of the system. Where clubmoss (*Selaginella densa*) is a problem, mechanical treatment such as chiseling or disking may decrease the clubmoss and improve forage productic on sites with *Agropyron smithii* cover (Dolan and Taylor 1972).

Noted elsewhere.--Ross and others (1973) described at least 16 near-pristine stands scattered throughout central and eastern Montana that appear to fall within the *AGSP/AGSM* h.t. Ten of these were in foothill areas and six were on the sedimentary plains. All but one were in the 10- to 16-in (25- to 40-cm) precipitation zone and occurred on fine-sandy to clay-loam soils.

Agropyron spicatum/Poa sandbergii (MONT) h.t.

(*AGSP/POSAN* h.t.)

Distribution and environment.--Though not abundant, the *AGSP/POSAN* h.t. can be found scattered throughout western Montana. Usually it occurs at elevations between ,000 and 6,000 ft (900 and 1,800 m). It can be found on any exposure and on gentle as ell as very steep slopes. The type occurs on loamy soils derived from a wide variety f parent materials. It is considered a moderately arid type, probably falling within he 14- to 20-in (36- to 56-cm) precipitation zone. In the eight stands sampled, the mount of bare soil ranges from 1 to 30 percent and the amount of soil surface covered y rock ranges from 1 to 59 percent (appendix D).

Vegetative composition.--This grassland habitat type is clearly dominated by *gropyron spicatum* (fig 5); *Poa sandbergii* and *Koeleria cristata* are constant species f secondary importance. Neither rhizomatous *Agropyron* spp. nor *Bouteloua gracilis* are mportant. A *Stipa comata* phase (*STCO*) is recognized where either *Stipa comata* or *Stipa partea* share dominance with *Agropyron spicatum.* The habitat type has a wide variety of orbs which, as a class, sometimes comprise 30 to 40 percent canopy cover (appendix D); et, no one forb constantly shares dominance with *Agropyron spicatum* (appendix E2). *alsamorhiza sagittata*, a forb not present in previously described habitat types, is ocally abundant in some communities of this type west of the Continental Divide. As ith the other habitat types within the *Agropyron spicatum* series, *Artemisia frigida* nd *Gutierrezia sarothrae* are the most prevalent low shrubs. Medium shrubs, such as *hrysothamnus nauseosus* and *Chrysothamnus viscidiflorus* are sometimes present but do ot form a major part of the undisturbed community.

igure 5.--*Agropyron spicatum/Poa sandbergii* h.t. on a 40-percent southwest slope at 4,200 ft elevation east of Lonepine in northwestern Montana.

Productivity.--We did not measure the productivity of this habitat type in western ontana. However, productivity measures are available for similar range types in other reas.

Anderson (1956) reports that production from similar vegetation in eastern Oregon ranges between 200 lb/acre (224 kg/ha) on sandy soils to 500 lb/acre (560 kg/ha) on silty-loam soils. The major forage producers were *Agropyron spicatum* (20 to 65 percent), *Poa sandbergii* (20 to 25 percent), *Stipa* spp. (5 to 30 percent), and perennial forbs (5 to 10 percent).

For south central British Columbia, McLean and Marchand (1968) report yields of 420 to 500 lb/acre (470 to 560 kg/ha) for good to excellent range of this type. *Agropyron spicatum*, *Stipa comata*, *Poa sandbergii*, and *Artemisia frigida* were the primary producers.

In western Montana we can expect that good condition range in the *AGSP/POSAN* h.t. will probably produce between 300 and 500 lb/acre (336 to 672 kg/ha) total air-dry vegetation. Approximately 70 to 80 percent of this will consist of grasses that are good to excellent in palatability. However, if *Stipa comata* is abundant, value for mid-season grazing will be reduced because of possible mechanical damage to livestock from the awns of this species (Stoddart and Smith 1955).

Changing with grazing.--General reactions of species to overgrazing in the *Agropyron spicatum* series are discussed in the *AGSP/BOGR* h.t. section. Under heavy cattle or horse grazing, *Agropyron spicatum* is the principal forage species to decrease. Daubenmire (1940) found that this kind of use in the *AGSP/POSAN* h.t. in eastern Washington resulted in a marked decline of *Poa sandbergii* as well, but *Poa sandbergii* increased appreciably when the type was heavily grazed by sheep. The reverse appears to be true for *Balsamorhiza sagittata*. We have observed that where present in appreciable amounts, *Balsamorphiza sagittata* will usually increase when the type is grazed by cattle or horses and decrease substantially when grazed in the spring or early summer by sheep. Fall grazing is not detrimental to this forb (Mueggler 1950; Laycock 1967). Very likely *Stipa comata* will increase initially with a decline in the more palatable species, but it too will decline with continued heavy use. *Artemisia frigida* and *Gutierrezia sarothrae* usually increase conspicuously with overgrazing. *Artemisia tridentata* and *Chrysothamnus* spp. may eventually become dominant on badly depleted ranges of this type. *Bromus tectorum* and *Centaurea maculosa* are often conspicuous invaders in the *AGSP/POSAN* h.t.

Range management.--Livestock management in the *AGSP/POSAN* h.t. should be keyed primarily to the grazing sensitivity of *Agropyron spicatum*, as discussed in management for the *AGSP/BOGR* h.t. Where *Balsamorhiza sagittata* is prominent in the community, management of sheep grazing should be keyed to the growth requirements of this robust and productive forb. Blaisdell and Pechanec (1949) found that *Balsamorhiza sagittata* is most susceptible to damage from grazing when it is in full bloom. Heavy clipping at this time reduced herbage production the following year by 60 percent and reduced the number of flower stalks almost 95 percent. Grazing earlier in the season, before the appearance of flower stalks, or later, after the plants had cured, is not nearly as damaging. As with *Agropyron spicatum*, the detrimental effect of grazing *Balsamorhiza sagittata* apparently depends on the amount of herbage left to manufacture food for storage in the roots during the period prior to drying.

Noted elsewhere.--Daubenmire (1970) described *Agropyron spicatum/Poa secunda (sandbergii)* h.t. for eastern Washington that lacks the species diversity of our Montana *AGSP/POSAN* h.t. This type does not contain such species as *Artemisia frigida*, *Phlox hoodii*, *Chrysopsis villosa*, *Gutierrezia sarothrae*, *Gaura coccinea*, and *Koeleria cristata*, which are common to our type. Also, *Stipa comata* is very conspicuous in our *Stipa comata* phase, but is generally lacking in the eastern Washington type.

Festuca scabrella/*Agropyron spicatum* h.t.

(*FESC/AGSP* h.t.)

Distribution and environment.--*Festuca scabrella* occurs on both sides of the Con-inental Divide but is widespread only in western Montana north of approximately 46° atitude. Outliers of the species extend as far south as the Gravelly and Madison ountain ranges (Stickney 1960). The *FESC/AGSP* h.t., therefore, is confined primarily the northern half of the state. It occurs at elevations between approximately 3,000 nd 6,000 ft (900 and 1,800 m), on both level topography and steep slopes, and on all xposures. Stands west of the Divide are generally below 4,000 ft (1,200 m) elevation. is a moderately arid habitat type.

Soils from two stands representing the *FESC/AGSP* h.t. were classified as fine ertic Agriboroll of ustic moisture and frigid temperature regimens, and as fine-loamy ntic Haploboroll of aridic moisture and frigid temperature regimens (Munn and others 978). The soil solums have neutral pH, with free calcium carbonates at depths reater than 10 in (26 cm). Soil depth is variable, with an A horizon ranging at least rom 6 to 10 in (15 to 25 cm), and solum from 10 to 17 in (25 to 43 cm). The amount f surface rock averages about 5 percent, as does the amount of bare soil (appendix D). ne habitat type is not confined to any particular soil parent material.

Vegetative composition.--This is an obvious grassland type conspicuously dominated *Festuca scabrella* (fig. 6). Both *Agropyron spicatum* and *Festuca idahoensis* are enerally abundant; however, *Festuca idahoensis* may be absent on some areas east of ne Divide. In fact, somewhat different overall species composition exists between ommunities of this type found east and west of the Divide. *Artemisia frigida*, *Chrysopsis illosa*, *Gutierrezia sarothrae*, *Stipa comata*, *Bouteloua gracilis*, *Muhlenbergia cuspidata*, *iatris punctata*, and *Artemisia ludoviciana* are either more common or present only ast of the Divide. West of the Divide, *Balsamorhiza sagittata*, *Besseya wyomingensis*, *astelleja lutescens*, and *Lomatium triternatum* are more common.

igure 6.--*Festuca scabrella/Agropyron spicatum* h.t. on a southwest facing slope, 3,500 ft elevation, in the foothills west of Flathead Lake in northwestern Montana.

The flora of this habitat type is more complex than any of the types discussed so far. In some stands more than 50 species were recorded on the 20 X 20 m macroplot. Both graminoid and forb species are very numerous; shrubs, however, are scarce (appendix E3). *Lupinus sericeus* can be very prominent and productive, though it may not occur in all stands.

The *Stipa comata* phase (*STCO*) of the *FESC/AGSP* h.t. is characterized by the prevalence of *Stipa comata*, the greater abundance of *Bouteloua gracilis*, *Artemisia frigida*, and *Liatris punctata*, and lesser quantities of *Poa sandbergii* and *Antennaria rosea* than the remainder of the habitat type. Most of the stands in this phase were encountered east of the Divide.

Productivity.--This habitat type is more productive than any of the habitat types in the *Agropyron spicatum* or *Stipa comata* series. The range in productivity between stands within the type is not great; stands selected to span the range in productivity differed only about 35 percent. Variation between years attributable to weather is considerably greater--in one case more than 200 percent during a 3-year period. The differences in production between stands selected to represent the range in productivity within the habitat type in Montana, and a measure of variation between years are presented in table 5.

Table 5.--*Extremes in production and variability over a 3-year period in the* Festuca scabrella/Agropyron spicatum *habitat type*

Growth form	Stand 232 Average	Stand 232 SE[1]	Stand 87 Average	Stand 87 SE[1]
	Air-dry lb/acre			
Graminoids	792	94	792	194
Forbs	96	10	339	92
Shrubs	1	1	15	4
Total	890	84	1,201	289

[1]Standard error over a 3-year period.
[2]Multiply by 1.12 for kg/ha.

McLean and Tisdale (1972) reported production for similar vegetation in British Columbia as 441 to 1,055 lb/acre (460 to 1,182 kg/ha) for good to excellent range condition. Under poor range condition they found that annual production was reduced by half.

Grasses are by far the most productive class of vegetation in this type, unless the vegetation is severely altered by overgrazing. Such good to excellent forage species as *Festuca scabrella*, *Agropyron spicatum*, *Festuca idahoensis*, and *Koeleria cristata* (appendix F) are normally abundant (appendix E3). As a class, the graminoids make up between 65 and 90 percent of the total biomass. The forbs constitute from about 10 to 25 percent, and the shrubs seldom exceed 5 percent of the total biomass. Very few species of shrubs occur in this type. On the other hand, a large variety of forbs may be present despite their minor role in overall productivity. The most consistently abundant plants other than grasses are such relatively unpalatable species as *Artemisia frigida*, *Achillea millefolium*, *Lupinus sericeus*, *Antennaria rosea*, and *Cerastium arvense*. The *Stipa comata* phase can be expected to have greater quantities of *Artemisia frigida*, *Stipa comata*, *Allium cernuum*, and *Liatris punctata*, and less *Poa sandbergii*, *Antennaria rosea*, *Lupinus sericeus*, and *Cerastium arvense* than the remainder of the typ

Changes with grazing.--*Festuca scabrella*, the principal forage producer in this abitat type, is fairly sensitive to abusive grazing by cattle and horses. Consequently, t is the primary "decreaser" species. On range heavily overgrazed for many years, *estuca scabrella* plants often are changed from robust tussocks to small weak shoots nconspicuous among the other grasses and forbs. Sizable differences in canopy cover etween lightly and heavily grazed stands were apparent for several important species ithin the *Festuca scabrella* series, yet these differences lacked consistency. *Agro-ron spicatum* increased as well as decreased significantly on paired stands within his series (appendix G3) irrespective of habitat type. The literature supports this inding; *Agropyron spicatum* was shown as a decreaser in four references and as an ncreaser in three references for studies subsequently identified as related to the *estuca scabrella* series. The same sort of variable reaction to grazing can be scribed to *Festuca idahoensis*, which was shown as an increaser in five literature eferences and as a decreaser in two. Our stand data support this varied behavior rrespective of habitat type within the *Festuca scabrella* series. The status of *chillea millefolium* was unclear from our data; the literature, however, suggests trongly that it should be considered an increaser. The principal species that in-rease with overgrazing in this habitat type are *Artemisia frigida, Antennaria rosea, erastium arvense,* and *Chrysopsis villosa.*

The following categorization of species reactions to overgrazing in the *Festuca cabrella* series was developed from our differentially grazed communities and from our urvey of literature:

Decreasers	Increasers	Invaders
Agropyron [illegible]	*Achillea millefolium*	*Bromus tectorum*
Agropyron dasystachyum	*Anemone patens*	*Centaurea maculosa*
[illegible]	*Antennaria dimorpha*	*Cirsium vulgare*
Erigeron [illegible]	*Antennaria rosea*	*Poa pratensis*
Erigeron subtrinervis	*Antennaria umbrinella*	*Taraxicum officinale*
[illegible]	*Arenaria congestis*	*Tragopogon dubius*
Liatris punctata	*Arnica fulgens*	
Stipa richardsonii	*Artemisia frigida*	
	Artemisia tridentata	
	Artemisia ludoviciana	
	Aster campestris	
	Aster falcatus	
	Astragalus miser	
	Bouteloua gracilis	
	Carex filifolia	
	Carex pennsylvanica	
	Cerastium arvense	
	Chrysopsia villosa	
	Comandra umbellata	
	Chrysothamnus nauseosus	
	Danthonia intermedia	
	Danthonia parryi	
	Danthonia unispicata	
	Erigeron compositus	
	Gaura coccinea	
	Geum triflorum	
	Gutierrezia sarothrae	
	Helictotrichon hookeri	
	Huechera spp.	
	Juniperus horizontalis	
	Juncus balticus	
	Koeleria cristata	
	Muhlenbergia cuspidata	
	Poa sandbergii	
	Potentilla fruticosa	
	Phlox albomarginata	
	Phlox hoodii	
	Sphaeralcea coccinea	
	Solidago missouriensis	
	Stipa comata	
	Stipa occidentalis	
	Stipa spartea	

Class of livestock grazing the vegetation influences changes in composition. Since sheep find forbs more palatable than do cattle, such species as *Balsamorhiza sagittata*, *Vicia americana*, and *Geranium viscosissimum* are more likely to decline on overgrazed sheep range than on overgrazed cattle range.

Range management.--Although the *FESC/AGSP* h.t. is suitable for use by all classes of livestock, the predominance of robust tussock grasses favors use by cattle and horses. Tisdale and others (1954) and McLean and Marchand (1968) recommend a late spring and early fall season of use for range of this type.

Festuca scabrella, the major forage producer on good condition ranges in this type, s very sensitive to grazing. Johnson and MacDonald (1967) suggest that maintenance of *estuca scabrella*-dominated areas in climax or excellent condition may be impossible if razing is permitted. This is attributed to the erect, readily accessible growth and ighly palatable nature of the plant. Campbell and others (1962) recommend a grazing ntensity for *Festuca scabrella* prairie that will leave 40 to 50 percent carryover of he current year's growth and 20 percent of the seed stalks in order to maintain plant igor. Even this may be too heavy, for Johnston (1961) found that light grazing causes *estuca scabrella* to decline somewhat.

A deferred or rest-rotation system of grazing (Hormay and Talbot 1961) may be eneficial for ranges of this type. However, McLean and Tisdale (1972) found that even nder complete protection improvement from poor to excellent condition usually took 30 ears. More time was required to go from poor to fair condition than from fair to ood condition. They found that *Agropyron spicatum* recovered much more rapidly than *estuca scabrella*. Since complete protection for such long periods of time is usually ot economically acceptable management, they suggest grazing moderately in the fall or inter, when the plants are least susceptible, as a means of restoring depleted ranges.

Water development, fencing, and proper salting are methods for obtaining better istribution of livestock and more uniform use of the forage.

Noted elsewhere.--Similar vegetation in southern British Columbia has been described y Tisdale (1947) as the *Agropyron-Festuca* zone, and by Looman (1969) as the *Festuca cabrella/Agropyron spicatum* alliance. Looman indicates that this type generally is ound below 4,000 ft (1,200 m) elevation in British Columbia. Ross and others (1973) ist six stands of near-pristine vegetation in the foothill and Rocky Mountain areas of lontana that can be classified as *FESC/AGSP* h.t. Most of these occurred on loamy soils n the 15- to 19-in (38- to 48-cm) precipitation zone.

Festuca scabrella/Festuca idahoensis h.t.

(*FESC/FEID* h.t.)

Distribution and environment.--The *FESC/FEID* h.t. occurs on mountain slopes on oth sides of the Continental Divide, primarily north of 46° latitude. The type extends o slightly higher elevations, 3,000 to 7,000 ft (900 to 2,100 m), and is found on sites nore mesic than those occupied by the *FESC/AGSP* h.t. The type can occur on any exposure, but is generally confined to slopes less than 30 percent. This habitat type robably occurs primarily within the 20- to 30-in (50- to 75-cm) precipitation zone.

The *FESC/FEID* h.t. can be found on a wide variety of soil parent materials, ranging rom granitics to mixed glacial tills. Soils from three representative examples of this abitat type were classified as either Argic or Calcic Pachic Cryborolls. All were oamy and of ustic moisture and cryic temperature regimens (Munn and others 1978). olum depths ranged from 16 to 35 in (41 to 90 cm), with a 9- to 14-in (23- to 30-cm) horizon (appendix C2). Solum reaction varied from slightly acid to neutral, with ree calcium carbonates not encountered until at least the 22-in (57-cm) depth. Usually ery little bare soil or rock is exposed within this habitat type unless the vegetation s badly depleted (appendix D).

Vegetative composition.--Despite the great mixture of species within the *FESC/FEID* h.t., the vegetation is usually dominated by the two fescues, *Festuca scabrella* and *Festuca idahoensis* (fig. 7). In contrast to the *FESC/AGSP* h.t., *Agropyron spicatum* and shrubs are less conspicuous and may be absent; canopy cover of *Festuca scabrella*

tends to be greater; and *Danthonia intermedia*, *Stipa occidentalis*, and *Carex* spp. are more prevalent. Species diversity is also greater with a generally higher proportion of such forbs as *Geum triflorum*, *Galium boreale*, and *Campanula rotundifolia* (appendix E3). *Koeleria cristata* is a consistently occurring grass. *Lupinus sericeus* can be a dominant forb in this type, though it does not occur in all stands.

Figure 7.--*Festuca scabrella/Festuca idahoensis* h.t at 6,400 ft elevation near McDonald Pass west of Helena, Montana.

The *Geranium viscosissimum* phase (*GEVI*) is characterized by the presence and often abundance of *Geranium viscosissimum* and *Potentilla gracilis*. *Stipa occidentalis* and *Agropyron spicatum* are also generally more abundant here than in the remainder of the habitat type. Some of these more moist sites are marked by the conspicuous presence of *Stipa richardsonii* and substantial amounts of *Carex filifolia* and *Danthonia intermedia*. These have been designated the *Stipa richardsonii* phase (*STRI*). In most other respects, this phase is similar to the *Geranium viscosissimum* phase.

Danthonia parryi has been observed occasionally as a codominant with *Festuca scabrella* in northern Montana east of the Divide. Since species composition does not otherwise differ appreciably from the rest of the habitat type, a separate delineation did not appear appropriate.

Productivity.--We consider the *FESC/FEID* h.t. to be potentially one of the most productive upland forage types for cattle in western Montana. It produces at least one-half ton of air-dry vegetation per acre (1,120 kg/ha), most of which consists of palatable grasses. Differences between stands sampled for productivity did not exceed 45 percent. For the same stands, yearly differences between years attributable to weather amounted to as much as 100 percent. The data in table 6 represent the extremes in productivity of western Montana stands selected to sample this difference, and a measure of yearly variability in production due to weather.

Table 6.--*Extremes in production and variability over a 3-year period in the* Festuca scabrella/Festuca idahoensis *habitat type*

Growth form	Stand 304		Stand 308	
	Average	SE[1]	Average	SE[1]
	Air-dry lb/acre[2]			
Graminoids	833	5	1,510	310
Forbs	292	105	121	43
Shrubs	1	1	0	-
Total	1,125	110	1,631	353

[1]Standard error over a 3-year period.
[2]Multiply by 1.12 for kg/ha.

Data from Alberta (Johnston 1961), British Columbia (McLean and Marchand 1968), and Saskatchewan (Campbell and others 1962) suggest a wide range of productivity for Canadian vegetation similar to this habitat type. This variation is probably attributable to both environmental differences and to range condition. The range in herbage production, summarized by condition class, for this Canadian vegetation is:

Condition class	*Range in lb/acre*
Excellent	426 to 2,278
Good	412 to 1,866
Fair	420 to 1,339
Poor	368 to 854

Based on our productivity studies in Montana, 70 to 90 percent of the total biomass for this habitat type is composed of graminoids. The remainder is forbs; shrubs are only incidental. Between 30 and 85 percent of the biomass consists of *Festuca scabrella*. The other generally important forage species is *Festuca idahoensis*. Some fairly important producers in the *Geranium viscosissimum* phase of this habitat type are *Agropyron spicatum*, *Stipa occidentalis*, and *Geranium viscosissimum*; and in the *Stipa richardsonii* phase are *Carex filifolia*, *Danthonia intermedia*, and *Stipa richardsonii*.

A wide variety of other graminoids and forbs may also occur in this habitat type. *Achillea millefolium*, *Arenaria congesta*, *Cerastium arvense*, *Geum triflorum*, and *Potentilla gracilis*, all species with low palatability, are usually the most abundant forbs.

Changes with grazing.--A general listing of the reaction of plants to grazing in the *Festuca scabrella* series is given in the description for the *FESC/AGSP* h.t. *Festuca scabrella* is the major species that declines with heavy cattle or horse use. We found that *Festuca idahoensis* declines in some instances of heavy grazing, but more often than not it increases. Characteristically, lightly grazed stands in this type are dominated by *Festuca scabrella*, and heavily overgrazed stands are dominated by *Festuca idahoensis*. Other principal species that increase are *Koeleria cristata*, *Carex filifolia*, *Geum triflorum*, and various species of *Danthonia*. Very heavy use, particularly by sheep, may reduce the amount of such species as *Geum triflorum* and *Geranium viscosissimum* that tend to increase under less intensive grazing. This reaction is illustrated by the data for stands 241 and 242 in appendix G3.

Range management.--Grazing in this type can take place from late spring until early fall at the lower elevations. At the higher elevations west of the Continental Divide and on most of the type occurring east of the Divide, grazing may be confined to the summer months. The relative abundance of both grasses and forbs, particularly in the *Geranium viscosissimum* phase, make this habitat type well suited to all classes of livestock.

Cattle grazing in this series should be keyed primarily to the reaction of *Festuca scabrella*. Not only is it usually the major forage producer but it is highly sensitive to grazing as well. Sheep grazing should be keyed to the reaction of such important forbs as *Geranium viscosissimum*. Even light continuous summer grazing can cause changes in vegetation composition. Johnston (1961) found that light grazing by cattle in this type favored *Danthonia parryi* to the detriment of *Festuca scabrella*. Light grazing resulted in greater diversity of plant species, greater total basal area, and a greater amount of root material than in an ungrazed area. Campbell and others (1962) found that heavy cattle grazing during the summer in this type of vegetation in Canada severely reduced *Festuca scabrella* and increased shrubby and weedy species; even moderate grazing, 1-1/2 acres (0.6 ha) per cow-calf month, reduced *Festuca scabrella* about one-third below that of light grazing, but did not appreciably affect *Festuca idahoensis*. In their study 2 acres (0.8 ha) per cow-calf month summer long was considered light grazing.

Deferred-rotation and rest-rotation systems of grazing may be used to advantage in the *Festuca scabrella* series. Rest-rotation appears best suited for ranges with adverse topographic conditions, as is often the case for the *FESC/FEID* h.t. However, rest-rotation may not be as desirable as deferred rotation for improving density of *Festuca scabrella*.

Fencing, water development, and salting can often be used to advantage in this habitat type for obtaining better livestock distribution and more uniform forage utilization.

Noted elsewhere.--Ross and others (1973) list 16 stands of near-pristine vegetation in the Rocky Mountain and foothill areas of Montana that can be classified as being in the *FESC/FEID* h.t. Most of these occur in the 15- to 19-in (38- to 48- cm) precipitation zone on loamy or gravelly loam soils. Similar vegetation in western Alberta has been described by Stringer (1973) as the *Festuca-Danthonia* prairie. Looman (1969) described similar vegetation that occurs on warm slopes in the southern foothills of the Canadian Rocky Mountains as the *Festuca scabrella/Danthonia intermedia* association.

Festuca idahoensis/Agropyron smithii h.t.

(*FEID/AGSM* h.t.)

Distribution and environment.--In Montana this habitat type is confined almost exclusively to areas east of the Continental Divide, but it ranges from the Canadian border to Wyoming. It occurs on relatively gentle slopes (less than 15 percent) where the plains join the mountains. The type has been found as high as 8,000 ft (2,400 m) in elevation, but most of the time it will be found between 4,000 and 6,000 ft (1,200 and 1,800 m). Soils are usually moderately deep and of sedimentary origin. The soil is usually well covered by vegetation. In the stands we sampled, the amount of bare soil ranged from 1 to 8 percent and the amount of soil covered by rock ranged from 1 to 18 percent.

Vegetative composition.--All habitat types within the *Festuca idahoensis* series are characterized as grasslands where *Festuca idahoensis* is one of the dominant graminoids and where *Festuca scabrella*, if present at all, is a very minor part of the community. The *FEID/AGSM* h.t. is differentiated from the other habitat types in the series by the presence and often abundance of rhizomatous wheatgrasses (*Agropyron smithii* and/or *Agropyron dasystachyum*), and the absence or scarcity (less than 5 percent canopy

cover) of *Agropyron spicatum* (fig 8). Grasses are usually far more abundant than either forbs or shrubs. *Poa cusickii* is often conspicuous and is associated with or replaces *Poa sandbergii*. *Koeleria cristata* is also a prominent grass in this habitat type. *Phlox hoodii*, *Gaillardia aristata*, *Antennaria rosea*, and *Achillea millefolium* are usually the most prominent forbs (appendix E4). Shrubs, if present, are usually scattered; *Artemisia frigida* is the only shrub with high constancy.

Figure 8.--*Festuca idahoensis/Agropyron smithii* h.t. on rolling foothills at 5,100 ft elevation west of Bozeman in southwestern Montana.

Productivity.--We found that stands selected to span the range of site potential within the *FEID/AGSM* h.t. exhibited an 80 percent difference in total production. Even greater variation in annual production can be caused by yearly weather differences. Over a period of three consecutive years, one stand produced 110 percent more herbage in the high year than in the low year. The extremes in production between the stands we sampled in Montana and a measure of the variation between years are presented in table 7.

Table 7.--*Extremes in production and variability over a 3-year period in the* Festuca idahoensis/Agropyron smithii *habitat type*

Growth form	Stand 217 Average	Stand 217 SE[1]	Stand 171 Average	Stand 171 SE[1]
	Air-dry lb/acre[2]			
Graminoids	354	24	1,118	61
Forbs	344	107	168	77
Shrubs	21	9	6	6
Total	719	108	1,292	131

[1]Standard error over a 3-year period.
[2]Multiply by 1.12 for kg/ha.

Grasses usually comprise about 80 percent of the total production in this type. However, as shown in the data for stand 217 (table 7), forbs can be abundant, although this is an exception. Shrubs are generally only a minor component.

Festuca idahoensis, *Agropyron smithii*, and *Agropyron dasystachyum* are the primary forage producers. Usually *Festuca idahoensis* makes up 30 to 60 percent of the total biomass and the rhizomatous wheatgrasses make up from 10 to 60 percent. *Koeleria cristata*, *Poa cusickii*, and *Poa sandbergii*, also desirable forage species, occur in lesser quantities. Forbs and shrubs usually consist of such low-value forage species as *Phlox hoodii*, *Gaillardia aristata*, *Achillea millefolium*, and *Artemisia frigida*.

Changes with grazing.--*Festuca idahoensis* is the principal forage species that declines with overgrazing in this habitat type. Although *Agropyron smithii* is very palatable, neither it nor *Agropyron dasystachyum* apparently respond consistently to grazing--in some cases they decrease and in others they increase. The principal species that increase are *Artemisia frigida*, *Poa sandbergii*, *Poa cusickii*, and possibly *Koeleria cristata*. A generalized listing of the response of species in the *Festuca idahoensis* series is given in the discussion of the *FEID/AGSP* h.t.

Range management.--The fairly low elevational occurrence of much of this habitat type makes it suitable for grazing in either the spring, summer, or fall. However, repeated heavy use in early summer when carbohydrate reserves in the grasses are likely to be at a low point may be very harmful to the vegetation. The higher elevation areas can usually be used only in the summer. The type is best suited for use by cattle and horses because of the predominantly graminoid vegetation.

Unfortunately, management information that can be identified specifically to this and many of our other minor habitat types is lacking in the literature. Consequently, management guides must be inferred from the known requirements and reactions of the major species as they occur in other better-understood vegetation types. *Festuca idahoensis*, the rhizomatous wheatgrasses (*Agropyron smithii* and *Agropyron dasystachyum*) and the *Poa* spp. are the major forage producers in the *FEID/AGSM* h.t. Information discussed in the *FEID/AGSM* h.t. and *AGSP/AGSM* h.t. sections regarding management of these species may be applicable in this habitat type as well.

Festuca idahoensis/Agropyron spicatum h.t.

(*FEID/AGSP* h.t.)

Distribution and environment.--This is perhaps the most frequently encountered mountain grassland habitat type in southwestern Montana. Although it occurs throughout the western part of the State, it is particularly prevalent on intermediate elevation mountain slopes south of 46° latitude. The type can be found at elevations ranging from 4,500 to 7,500 ft (1,400 to 2,300 m). It tends to occur more on northerly exposures at the lower elevations and on southerly exposures at the higher elevations. The *Stipa occidentalis* phase (*STOC*) is usually found at the higher elevations. Percent slope is not restrictive. This is a moderately mesic grassland type that probably occurs primarily within the 14- to 20-in (35- to 50-cm) precipitation zone.

Soils from four representative stands of the *FEID/AGSP* h.t. were either Typic Haploboroll, or Typic or Calcic Cryoboroll; all were of ustic moisture and cryic temperature regimens (Munn and others 1978). The soils had an 8- to 11-in (21- to 28-cm) A horizon, and a 17- to 35-in (44- to 89-cm) solum depth. The solum was neutral to slightly alkaline. Free calcium carbonate was encountered at depths ranging from 8 to 35 in (21 to 90 cm). This habitat type occurs on a wide variety of soil parent materials. The amount of soil surface covered by rock ranged from 0 to 40 percent, whereas the amount of bare soil ranged from 0 to 25 percent (appendix D).

Vegetative composition.--*Agropyron spicatum* is always present and more abundant than any of the rhizomatous wheatgrasses, and usually is an obvious codominant with *Festuca idahoensis* (fig. 9). Although a wide variety of other graminoids can occur in this type, *Koeleria cristata, Poa sandbergii,* and either *Stipa comata* or *Stipa occidentalis* are the only ones that are usually present and form substantial canopy cover. The amount of forbs is highly variable, ranging from 10 to 60 percent canopy cover. *Achillea millefolium, Antennaria rosea, Arenaria congesta,* and possibly *Phlox hoodii* are the forbs that occur most consistently (appendix E4). *Lupinus sericeus*, if present, can form a major part of the plant community. Medium shrubs such as *Chrysothamnus viscidiflorus* and *Artemisia tridentata* may occasionally be present, but they are never abundant unless the type has been severely disturbed.

Figure 9.--*Festuca idahoensis/Agropyron spicatum* h.t. on a north west facing clope at 5,200 ft elevation in the foothills west of Bozeman. This is one of the most frequently encountered types in southwestern Montana.

The more moist *Stipa occidentalis* phase is characterized by conditions where *Stipa occidentalis* is more freauent and abundant than *Stipa comata.* Such species as *Agropyron caninum, Danthonia intermedia, Geum triflorum, Agoseris glauca, Campanula rotundifolia, Cerastium arvense, Gaillardia aristata,* and *Galium boreale* are more likely to be a prominent part of the vegetation in this phase than in the remainder of the habitat type.

Productivity.--We sampled four different stands over a 3-year period to evaluate the productivity potential of the *FEID/AGSP* h.t. in western Montana. These stands were selected to span the range in site potential within the type. The best site produced almost twice as much biomass as the poorest site. Production appeared to be greater on the northerly exposures, suggesting that lower insolation and greater moisture availability may be partly responsible for differences in site potential. Production of a stand varied as much as 56 percent over the 3-year period because of yearly weather differences. The extremes in production between the stands we sampled in this type and the standard error of differences in production between years are presented in table 8.

Table 8.--*Extremes in production and variability over a 3-year period in the* Festuca idahoensis/Agropyron spicatum *habitat type*

Growth form	Stand 27		Stand 28	
	Average	SE[1]	Average	SE[1]
	Air-dry lb/acre[2]			
Graminoids	271	21	465	91
Forbs	385	52	827	107
Shrubs	1	1	0	--
Total	655	73	1,293	173

[1]Standard error over a 3-year period.
[2]Multiply by 1.12 for kg/ha.

Daubenmire (1970) found that protected vegetation of a similar type in eastern Washington produced approximately 1,300 lb/acre (1,450 kg/ha) of which 60 percent was perennial grasses. Vogel and Van Dyne (1966) found vegetation of this type in southwestern Montana producing 660 lb/acre (770 kg/ha) on a protected site and 590 lb/acre (660 kg/ha) on a grazed site. In their study approximately 70 percent was graminoids. In other studies in southwestern Montana, Mueggler (1972b) found that a stand at the drier end of the *FEID/AGSP* h.t. produced between 605 and 818 lb/acre (678 and 916 kg/ha) over a 5-year period; about 60 percent of this production consisted of graminoids. A stand on a more mesic northerly exposure within this habitat type produced from 724 to 1,599 lb/acre (810 to 1,790 kg/ha) over a 5-year period, of which only 26 percent was graminoids. Mueggler (1972b) found that herbage production fluctuated considerably more between years on the more productive northerly aspects than on the southerly aspects.

The proportion of forbs to graminoids differs appreciably between stands within this habitat type. Overall, however, forbs form a greater proportion of the vegetation in the *FEID/AGSP* h.t. than in any of the previously described types. They are especially abundant within the relatively mesic *Stipa occidentalis* phase of this habitat type.

Graminoid production in our stands ranged between 35 and 70 percent of the vegetation. Most of these grasses are considered good forage species. Between 30 and 65 percent of the total production consisted of forbs, most of which are fairly low in palatability. The proportion of grasses to forbs in a stand did not change more than about 25 percent as a result of yearly weather differences. In none of the four stands sampled did shrub production exceed 5 percent of the total biomass.

Festuca idahoensis and *Agropyron spicatum* are the two species that produce the most forage within this habitat type. Together they usually comprise between 30 and 65 percent of the total air-dry production. Other important forage producers in the *Stipa occidentalis* phase are *Carex petasata* and *Stipa occidentalis*. The most abundant forbs, *Achillea millefolium, Phlox hoodii, Cerastium arvense, Lupinus sericeus, Geum triflorum,* and *Antennaria rosea* are generally poor forage species.

Changes with grazing.--*Agropyron spicatum* and *Festuca idahoensis* are the principal species that decrease with heavy grazing in this habitat type. In some instances, *Festuca idahoensis* may increase with the reduction of *Agropyron spicatum*, but it will eventually decrease with continued heavy use. The principal species that usually increase are *Artemisia frigida, Poa sandbergii, Cerastium arvense,* and *Phlox hoodii*. The response of *Lupinus* spp. and *Koeleria cristata* are variable and defy general categorization.

Summarized below is a listing of species in the *Festuca idahoensis* series accord-
ng to general response to grazing. This list was developed from our data on differen-
ially grazed paired stands and from information contained in literature.

Decreasers	Increasers	Invaders
goseris glauca	*Achillea millefolium*	*Bromus tectorum*
gropyron caninum	*Arnica fulgens*	*Centaurea maculosa*
gropyron spicatum	*Artemisia frigida*	*Cirsium vulgare*
ster integrifolius	*Campanula rotundifolia*	*Poa pratensis*
romus marginatus	*Carex petasata*	*Taraxicum officinale*
repis spp.	*Carex stenophylla*	*Tragopogan dubius*
rigeron caespitosus	*Cerastium arvense*	
estuca idahoensis	*Chrysopsis villosa*	
eranium viscosissimum	*Chrysothamnus nauseosus*	
esperochloa kingii	*Danthonia intermedia*	
upinus spp.	*Danthonia unispicata*	
oa ampla	*Erigeron compositus*	
oa interior	*Erigeron filifolius*	
otentilla gracilis	*Gaura coccinea*	
tipa viridula	*Geum triflorum*	
icia americana	*Helictotrichon hookeri*	
	Hymenoxys acaulis	
	Gutierrezia sarothrae	
	Koeleria cristata	
	Pendicularis contorta	
	Phlox hoodii	
	Poa cusickii	
	Poa sandbergii	
	Potentilla diversifolia	
	Solidago missouriensis	
	Stipa comata	
	Stipa lettermanii	
	Stipa occidentalis	

The literature suggests that *Carex obtusata, Antennaria rosea, Astragalus miser,* nd *Phlox multiflora* increase with grazing in this series, but our data (appendix G4) ndicate the opposite; therefore, we did not assign these four species to either ategory. Both *Chrysothamnus viscidiflorus* and *Tetradymia canescens* decreased signifi- antly on the grazed member of paired stands 112 and 113, but this is attributed to lk and deer winter browsing. If anything, these two shrubs probably increase under ummer grazing by livestock. Prolonged heavy use of the *FEID/AGSP* h.t. may also encour- ge a great increase in the abundance of *Artemisia tridentata. Bromus tectorum* is the rincipal annual species that invades this type.

Range management.--Although the *FEID/AGSP* h.t. is perhaps best suited for cattle roduction, the abundance of forbs, particularly in the *Stipa occidentalis* phase, makes t acceptable sheep range. At lower elevations the type can be used by livestock in he spring, summer, and fall. Use is usually not possible at midelevations until arly summer and can continue well into the fall. Use at the highest elevations is enerally confined to midsummer and early fall because of the lag in plant development nd likelihood of late spring and early fall snows.

The type is widely used by big game animals. Consequently, the resource manager should be alert to potential conflicts between wildlife and livestock. The type is used by elk and deer at the lower elevations as winter range, and by antelope year-round. For example, elk in the Elkhorn Mountains apparently spend all of their time from January through March in this type, subsisting on a diet of 75 percent dried grasses and 25 percent forbs (Stevens 1966). At intermediate elevations, the type is important spring-fall range, and at the highest elevations summer range for elk and deer. These wild ungulates commonly migrate upward in the spring following the snow line to graze avidly on fresh green herbage. Fall snow storms start the animals on their return migration to lower elevations where they winter. Stevens (1966) concluded that a potential conflict exists in this type between summer and fall use by cattle and fall-winter-spring use by elk. He also concluded that a potential conflict exists in summer use of the type by elk and sheep because of the high proportion of forbs in the summer diets of both. Certain sites at moderately high elevations are used by bighorn sheep and Rocky Mountain goats as winter range.

Proper use of the type under cattle grazing should be keyed primarily to the sensitivities of *Agropyron spicatum*, as discussed in management of the *AGSP/BOGR* h.t. The other principal forage grass, *Festuca idahoensis*, is not nearly as sensitive to abusive grazing because of its lower growth stature and lower palatability. *Festuca idahoensis*, however, is a valuable forage producer and deserves consideration in management. Its protein content, for example, apparently remains higher than that of *Agropyron spicatum* and other grasses during the latter part of the growing season (Skovlin 1967; Beath and Hamilton 1952; Pond and Smith 1971). *Festuca idahoensis* appears most sensitive to heavy defoliation at approximately the same stage of growth as *Agropyron spicatum*; that is, from flowering to seed ripening (Mueggler 1967). The calendar dates of the sensitive growth stages of these two important forage grasses coincide reasonably well (Mueggler 1972b), which simplifies management.

The resource manager must remain aware of weather-induced variability in rate of plant development from year to year. During a 5-year period, Mueggler (1972b) found that the appearance of flower culms in *Festuca idahoensis* differed as much as 4 weeks and blooming differed as much as 1 week; appearance of flower stalks in *Agropyron spicatum* varied more than 2 weeks and blooming 1 week. During a 5-year period, Pond and Smith (1971) report almost a 4-week difference in the date when *Festuca idahoensis* in northern Wyoming reached the "heads showing" development stage. The time when these mountain grassland species reach given developmental stages also differs with topography. Hopkins' Bioclimatic Law (Hopkins 1938) suggests a 10-day lag in plant development for each 1,000 ft (304 m) elevational rise. Mueggler (1972b), however, found that in the Gravelly Range of southwestern Montana, *Festuca idahoensis* at 8,200 ft (2,500 m) bloomed on the average 16 days later than it did at 7,100 ft (2,160 m). He also found that *Festuca idahoensis* bloomed an average 4 days later and *Agropyron spicatum* an average of 2 days later on northeasterly exposures than on southwesterly exposures.

The amount of use *Agropyron spicatum* and *Festuca idahoensis* can sustain without adversely affecting vigor is not easily generalized. It depends upon numerous considerations, the foremost ones being the time in the plant's development cycle when the use occurs, the type of grazing system used, and local site conditions. For example, Beetle and others (1961) found that although *Festuca idahoensis* could withstand moderate continuous grazing (40 to 45 percent utilization) on sedimentary soils, even light grazing reduced its vigor on granitic soils. The only reliable approach for determining proper use under any given situation and grazing system is to observe the reaction of the vegetation over a period of years. If the vigor of key forage species is being reduced, if young plants are not becoming established, if undesirable plants are increasing, and if soil disturbance is unacceptable, then either stocking rates or grazing systems should be altered.

Once the vigor of the principal forage grasses is reduced, recovery may be slow. .though Hcrmay and Talbot (1961) indicate that *Festuca idahoensis* in northern California ıat had suffered a vigor loss equivalent to half its basal area recovered fully after seasons of rest, a much longer period may be required in Montana. Mueggler (1975) ›und that although *Festuca idahoensis* of moderately low vigor in the *FEID/AGSP* h.t. ›quired 3 years of rest to regain full vigor, those with even lower vigor produced ıly two-thirds as much herbage and two-thirds as many flower stalks as normal plants ‹en after 5 years of rest. He also found that *Agropyron spicatum* is more sensitive › heavy use than *Festuca idahoensis* and recovers more slowly. He indicated that ›covery of moderately low vigor *Agropyron spicatum* would require at least 6 years of ›st, and very low vigor plants would require more than 8 years of rest.

As discussed in the *AGSP/BOGR* h.t. description, vigor of *Agropyron spicatum* can be ›sessed by comparing both numbers of flowering culms and maximum culm lengths between ›azed and protected plants. Vigor determinations for *Festuca idahoensis* also depend ›on comparison of grazed and protected plants because of yearly differences in plant :tributes caused solely by weather. Evanko and Peterson (1955) and Pond (1960) ıggested that leaf length, basal area, and herbage weight were of almost equal value ı determining vigor of *Festuca idahoensis*. Hurd (1959) indicated that maximum leaf ›ngth alone was a reliable vigor index. Mueggler (1970) suggested that the number of .ower stalks was the most sensitive indicator of vigor for this grass. He later ›ncluded that maximum leaf length was more reliable and potentially useful, particu-ırly when expressed in terms of differences in productivity by means of a regression ıuation (Mueggler 1975).

Judging from the literature, a rotation system of grazing may be of questionable ılue in a vegetation type where *Festuca idahoensis* is a major dominant. Smith and :hers (1967) found that rotation grazing failed to benefit this major forage species ı the Big Horn Mountains of Wyoming. Pond and Smith (1971) suggest that where rota-.on and rotation-deferred grazing systems appear to have benefited the range, the ıprovements probably result from the additional fencing, water development, and ıgebrush spraying that usually accompanies the change in grazing systems. Ratliff ıd Reppert (1974) found that in northern California moderate, continuous grazing per-ıtted *Festuca idahoensis* to maintain its vigor; a rest-rotation system neither reduced ›r improved the vigor of this grass, but may hold vigor at a higher level than does ›ntinuous grazing. Furthermore, they concluded that range managers cannot reliably ›y seed production into a rest-rotation system because of the strong relationship ›tween high seed production and high spring precipitation. They recommend that to ıhance establishment of new plants a pasture should be grazed only lightly until fter seed ripening in those years when spring precipitation is good and flower stalks ›ofuse; concentrating livestock on the pasture after seed ripening would then tend to ›ample the seed into the soil.

Fencing, water development, and proper salting contribute to better livestock istribution and greater uniformity of use in this type. Fertilization may also be an ffective tool to improve livestock distribution as well as to increase forage produc-ion. In eastern Washington, production of *Festuca idahoensis* was quadrupled by ›plication of 20 lb/acre (22 kg/ha) of N (Patterson and Youngman 1960). Although ›rtilization with 68 lb/acre (76 kg/ha) N in Wyoming did not significantly improve rass production, it did effectively increase utilization of a lightly used area for : least 2 years (Smith and Lang 1958).

Noted elsewhere.--Daubenmire (1970) described an *Agropyron spicatum/Festuca dahoensis* h.t. for eastern Washington that contains the same dominant grasses as the ›ntana *FEID/AGSP* h.t. but differs appreciably in secondary species. His type gener-ılly lacks such species as *Artemisia frigida, Koeleria cristata, Antennaria rosea, ›enaria congesta, Phlox hoodii*, and *Agoseria glauca* that are common in the Montana ‹pe. The *Agropyron-Festuca* community type described by Hall (1973) for Oregon and

the *Agropyron spicatum/Festuca idahoensis* association described by Franklin and Dyrness (1969) for the Columbia Basin bear more resemblance to Daubenmire's *AGSP/FEID* h.t. than to our Montana type. McLean (1970) described a *Festuca idahoensis/Eriogonum heracleoides* type occurring in the Similkameen Valley of British Columbia that is somewhat similar to our *FEID/AGSP* h.t. except for its abundance of *Eriogonum heracleoides* and lack of *Koeleria cristata, Phlox hoodii,* and *Antennaria rosea.*

Festuca idahoensis/Agropyron caninum h.t.

(*FEID/AGCA* h.t.)

Distribution and environment.--The *FEID/AGCA* h.t. is found on moderate to high elevation mountain slopes primarily east of the Continental Divide and south of 47° latitude. It commonly occurs on rather gentle slopes at elevations ranging from 6,500 to 8,600 ft (2,000 to 2,600 m). This is a moderately mesic habitat type, which probably falls within the 18- to 30-in (45- to 75-cm) precipitation zone. However, the relatively high elevations create fairly low potential evapotranspiration and a short growing season (appendix C1). The *Geranium viscosissimum* phase (*GEVI*) of this habitat type is slightly more mesic and tends to occur on easterly and northerly exposures.

Soils from selected stands in the *FEID/AGCA* h.t. were classified as either Argic or Pachic Cryoborolls of ustic moisture and cryic temperature regimens (Munn and others 1978). The loamy-soil A horizons ranged from 9 to 22 in (23 to 56 cm) thick, and the solums from 15 to 49 in (38 to 124 cm). The soils were slightly acid (pH from 6.0 to 6.5) and free calcium carbonates occurred only at depths greater than 37 in (95 cm). Amount of bare soil surface averaged 4 percent and ranged as high as 13 percent for the 16 stands sampled in this habitat type (appendix D). The type was found on a wide variety of soil parent materials.

Vegetative composition.--Although the *FEID/AGCA* h.t. has a predominantly grassland aspect (fig. 10), it has a higher proportion of forbs (30 to 70 percent canopy cover) than most of the other western Montana habitat types. *Festuca idahoensis* is usually the dominant grass. *Agropyron canium* is consistently present and is the dominant wheatgrass. Other usually important graminoids in this type include *Stipa occidentalis, Koeleria cristata, Danthonia intermedia,* and *Carex petasata* (appendix E4). Usually abundant forbs include *Geum triflorum, Potentilla gracilis, Achillea millefolium, Agoseris glauca, Campanula rotundifolia,* and *Arenaria congesta.* Shrubs are very scarce.

The more mesic *Geranium viscosissimum* phase is characterized by the abundance of *Geranium viscosissimum* and *Potentilla gracilis*, and the presence of either *Bromus carinatus* or *Bromus anomalous* and *Poa juncifolia.*

gure 10.--*Festuca idahoensis/Agropyron caninum* h.t. occurring on deep loessal soils within the Cliff Lake Research Natural Area, 7,000 ft elevation, in Madison County, southwestern Montana.

Productivity.--This is one of the most productive grassland habitat types in uthwestern Montana. Only the *DECA/CAREX* mountain meadows are likely to produce re. Three stands selected to span the range in productivity within the type differed much as 30 percent in total production. During a 3-year period, however, one stand oduced more than twice as much herbage in the high year as in the low year because yearly weather differences. Generally, the *Geranium viscosissimum* phase produces re total plant biomass than the rest of the habitat type. Extremes in production tween our stands, and the variability caused by weather are presented in table 9.

ble 9.--*Extremes in production and variability over a 3-year period in the* Festuca idahoenis/Agropyron caninum *habitat type*

rowth form	Stand 125		Stand 56	
	Average	SE[1]	Average	SE[1]
	Air-dry lb/acre[2]			
aminoids	368	--	907	96
rbs	825	--	765	88
rubs	0	--	0	--
Total	1,194	--	1,672	137

[1]Standard error over a 3-year period.
[2]Multiply by 1.12 for kg/ha.

Our production figures are somewhat lower than those obtained in other studies on this type of vegetation in Montana. For example, Branson and Lommasson (1958) recorded total air-dry weights of 2,100 and 2,300 lb/acre (2,350 and 2,575 kg/ha) on two sites. Mueggler (1967) obtained total production figures varying from 1,615 to 2,622 lb/acre (1,809 to 2,937 kg/ha) over a 3-year period (1963 through 1965) on a luxuriant *FEID/AGCA* grassland. In the Big Horn Mountains of Wyoming, Hurd (1961) obtained total production figures ranging from 1,120 to 3,311 lb/acre (1,254 to 3,708 kg/ha) in vegetation similar to this habitat type.

The proportion of graminoids in the stands we measured for production ranged from 30 to 60 percent. Generally, forbs formed a greater proportion of the total in those years when overall production was high than when it was low--or, forbs appeared more responsive than the grasses to a good growing year. Shrubs are rare. A wide variety of grasses and sedges, most of which are relatively good forage species, occur in this type. Seldom does a single species predominate. Ordinarily, *Festuca idahoensis* is the most abundant grass, but it seldom constitutes more than 20 percent of the total production. Other important forage species may be *Bromus carinatus, Agropyron caninum, Koeleria cristata,* and possibly *Stipa occidentalis* and *Danthonia intermedia*. A wide variety of forbs usually occur in this type. Most of these are considered lower in palatability than the grasses; thus, their contribution to usable forage is probably less than the amount suggested by their total biomass.

Changes with grazing.--Heavy grazing of the *FEID/AGCA* h.t. will result in a pronounced decrease of such forage producers as *Agropyron caninum, Bromus carinatus, Bromus anomalus,* and *Festuca idahoensis*. Possibly *Geranium viscosissimum, Lupinus* spp., and perhaps *Potentilla gracilis* will also decrease if heavily grazed by sheep. The species most likely to increase are *Danthonia intermedia, Geum triflorum, Solidago missouriensis Polygonum bistortoides,* and *Achillea millefolium*. The carices, *Carex petasata, Carex stenophylla,* and *Carex obtusata,* also are likely to increase. Substantial increases in *Artemisia tridentata* ssp. *vaseyana* may occur in this habitat type if the type is continually abused. The principal invading species is *Cirsium vulgare*. A general listing of the reaction of species to grazing in the *Festuca idahoensis* series is given in the discussion for the *FEID/AGSP* h.t.

Range management.--The abundance and variety of forbs in the *FEID/AGCA* h.t., particularly in the *Geranium viscosissimum* phase, make it one of the better types for summer grazing by sheep. It is also suitable as summer cattle range because of the abundance of graminoids. Use is generally limited to midsummer because of the lateness in development of the vegetation at these higher elevations and the probability of late spring and early fall storms. Elk, deer, and even moose frequent the type throughout the summer. Consequently, local conflicts may exist in coordinating livestock and wildlife use.

Management of the type as cattle range should be keyed to the reaction of the major perennial forage grasses, *Agropyron caninum, Bromus* spp., and *Festuca idahoensis*. When used as sheep range, the manager should consider the reaction of the major forbs as well. Mueggler (1967) determined that the three major forage grasses and two frequently abundant forbs (*Aster integrifolius* and *Potentilla gracilis*) are most sensitive to herbage removal when grazed during the period from early flowering to seed ripening. Julander (1968) found that *Geranium viscosissimum* was unable to withsta[illegible] repeated removal of 50 percent of its herbage during late flowering. This sensitive stage of growth is just prior to and during the early part of the period when plants store carbohydrates in roots and root crowns (McCarty and Price 1942). Repeated heavy use at this time can be very detrimental. However, the short length of the summer season when these areas are accessible to livestock severely limits grazing alternative on this very productive type. A rotation system of grazing would seem appropriate under such conditions.

Additional information on management of the *Festuca idahoensis* series that is pplicable to this habitat type is discussed in the *FEID/AGSP* h.t. section.

***Festuca idahoensis/Carex filifolia* h.t.**

(*FEID/CAFI* h.t.)

Distribution and environment.--This is an infrequent habitat type generally conined to the higher elevations in southwestern Montana. Examples were found in the ll Mountains north of Whitehall, the Gravelly Range south of Virginia City, and the oneer Mountains northwest of Dillon. The type occurs on rather gentle topography to 20 percent slope) in or near mountain saddles at elevations between 7,800 and 200 ft (2,400 and 2,800 m). Soils are typically well protected by plant growth and tter. Sampled stands had less than 5 percent bare soil and very little surface ck.

Vegetative composition.--The absence of a dominant *Agropyron* and the constant ssociation and abundance of *Carex filifolia*, *Danthonia intermedia*, *Geum triflorum*, d *Gentiana affinis* with *Festuca idahoensis* delineate this type (fig. 11) from others thin the *Festuca idahoensis* series. *Agropyron caninum* and *Carex petasata* are other nstant graminoids; *Carex rupestris* occasionally forms a substantial part of the mmunity. Other constant forbs include *Achillea millefolium*, *Agoseris glauca*, *tennaria rosea*, *Arenaria congesta*, *Cerastium arvense*, *Polygonum bistortoides*, and *tentilla* spp. (appendix E4). Shrubs are virtually nonexistent in this type.

igure 11.--*Festuca idahoensis/Carex filifolia* h.t. on Bull Mountain at 7,900 ft elevation near Whitehall in southwestern Montana.

Productivity.--We do not have a direct measure of productivity for this relatively nfrequent habitat type. However, its vegetation is morphologically similar to the ess productive portions of the *FEID/AGSP* h.t., which produce about 800 lb/acre (896 g/ha).

Judging from canopy-cover data (appendix E4), approximately 50 percent of the vegetation consists of fair to good forage species. *Festuca idahoensis*, *Carex filifolia*, and *Danthonia intermedia* comprise the bulk of this forage. Approximately 50 percent of the canopy cover is composed of forbs, most of which are low in forage value.

Changes with grazing.--A general listing of species response to grazing in the *Festuca idahoensis* series is given in the discussion of the *FEID/AGSP* h.t. The major forage species in the *FEID/CAFI* h.t. that will probably decrease with heavy grazing are *Festuca idahoensis* and *Agropyron caninum*. The primary species that will probably increase are *Danthonia intermedia*, *Achillea millefolium*, *Geum triflorum*, and *Antennaria rosea*. The response of *Carex filifolia* and *Carex petasata* will probably be to increase, at least initially.

Range management.--The *FEID/CAFI* h.t. is about equally suited for cattle or sheep grazing. Its high elevation occurrence restricts use to summer only. The type usually is confined by local topo-edaphic conditions and does not cover extensive areas. Consequently, management must be closely integrated with use of adjacent vegetation types. Management guides related to the primary forage grass, *Festuca idahoensis*, are discussed in the *FEID/AGSP* h.t. section.

Noted elsewhere.--Somewhat similar communities occur in the Big Horn Mountains of northern Wyoming. Hurd (1961) described a *Festuca idahoensis/Lupinus serecius* association there; the major difference betweeen it and our Montana *FEID/CAFI* h.t. is the prevalence of *Carex obtusata* as an associate in the Wyoming type instead of *Carex filifolia*. Despain (1973) also described *Festuca idahoensis* communities in that area in which the major associates are *Carex obtusata*, *Lupinus serecius*, and *Agroseris glauca*.

Festuca idahoensis/Stipa richardsonii h.t.

(*FEID/STRI* h.t.)

Distribution and environment.--This is another uncommon habitat type; however, it has been observed at widely scattered locations on both sides of the Continental Divide and in Yellowstone National Park. Sampled stands ranged widely in elevation from 3,600 to 6,900 ft (1,100 to 2,100 m), and occurred on rather gentle slopes and on moderately deep soils. Very little bare soil or surface rock was apparent. The *FEID/STRI* h.t. is considered a moderately mesic and relatively productive grassland type.

Vegetative composition.--The predominance of *Stipa richardsonii* (33 to 41 percent canopy cover) associated with *Festuca idahoensis* and the absence of a dominant *Agropyron* separate the *FEID/STRI* h.t. (fig 12) from other types in the *Festuca idahoensis* series. *Danthonia intermedia*, *Stipa occidentalis*, and *Geranium viscosissimum* are always present and usually abundant. A wide variety of other species is usually found, with *Potentilla gracilis*, *Chrysopsis villosa*, *Achillea millefolium*, *Galium boreale*, and *Carex petasata* being the more conspicuous. *Rosa askansana* is the only shrub that ever occurs in abundance. The often striking display of spreading flower panicles of *Stipa richardsonii* is characteristic of the type in mid- and late summer.

 

gure 12.--*Festuca idahoensis/Stipa richardsonii* h.t. at 6,880 ft elevation in Yellowstone National Park.

Productivity.--The structure of this uncommon type is similar to that of the less ıxuriant portions of the *FEID/AGCA* h.t., which produce about 1,200 lb/acre (1,344 ;/ha). Approximately 60 percent of this total, judging from canopy cover values ppendix E4), consists of graminoids which are relatively good forage species. *Stipa chardsonii* and *Stipa occidentalis* together make up about a third and *Festuca lahoensis* about a tenth of the total biomass. Low palatability forbs constitute oout 40 percent of the total vegetation. *Rosa arkansana*, the only shrub that occurs ı any abundance, averages about 3 percent of the total canopy cover.

Changes with grazing.--In this habitat type, *Festuca idahoensis, Agropyron caninum,* ıd *Geranium viscosissimum* generally are the principal forage species that decline ith heavy grazing. The status of *Stipa richardsonii, Stipa occidentalis,* and the rincipal shrub *Rosa arkansana* is unclear. The species most likely to increase under eavy grazing are *Danthonia intermedia, Chrysopsis villosa,* and possibly *Achillea llefolium* and *Galium boreale*. A listing of the general reaction of species to grazing ı the *Festuca idahoensis* series is given in the discussion of the *FEID/AGSP* h.t.

Range management.--This infrequent type appears equally suited as summer range or cattle or sheep. It generally produces an abundance of palatable grasses as well a wide variety of forbs. Management guides related to *Festuca idahoensis* are discussed ı the *FEID/AGSP* h.t. section. Specific requirements of the other major forage grasses re lacking. Proper management of the type probably will not differ appreciably from anagement appropriate for the *FEID/AGCA* h.t.; the environment and species are similar etween the two types except for the abundance of *Stipa richardsonii*.

Festuca idahoensis/Deschampsia caespitosa h.t.

(*FEID/DECA* h.t.)

Distribution and environment.--This is a subalpine meadow type (fig. 13) found on relatively gentle slopes at elevations between about 8,000 and 10,000 ft (2,500 and 3,000 m). Although not abundant, the type was encountered on both sides of the Continental Divide generally south of 47° latitude. The loamy soils are derived from a wide variety of parent materials. Soil surface is usually well protected, with bare soil averaging less than 3 percent for the eight stands sampled.

Figure 13.--*Festuca idahoensis/Deschampsia caespitosa* h.t. at 9,250 ft elevation on top of the Gravelly Range in southwestern Montana.

Vegetative composition.--*Deschampsia caespitosa* and *Festuca idahoensis* are the only constant graminoids and are generally the most productive ones in this high elevation grassland. Other graminoids commonly present in lesser quantities are *Agropyron caninum*, *Phleum alpinum*, *Luzula spicata*, *Danthonia intermedia*, and *Carex scirpoidea* (appendix E4). Forbs as a class are generally abundant, averaging 50 percent canopy cover. *Polygonum bistortoides*, *Potentilla diversifolia*, and *Trilfolium* spp. are the most constant; *Lupinus argenteus* and *Achillea millefolium* are sometimes abundant. Shrubby species are usually absent. At the highest elevations, *Festuca idahoensis* may be associated with or replaced by *Festuca ovina*.

Productivity.--We did not measure productivity of this habitat type. However, the vegetation appears structurally similar to that of the *FEID/AGCA* h.t., but with a somewhat shorter and perhaps denser cover. Total production probably ranges between 1,200 and 1,500 lb/acre (1,344 and 1,680 kg/ha), equally divided between graminoids and forbs. *Carex* spp. of only fair palatability may be common. *Festuca idahoensis* and *Deschampsia caespitosa* are the most consistently important forage producers. *Agropyron caninum*, *Stipa occidentalis* and *Danthonia intermedia* may be productive in some locations. A wide variety of forbs exists, most of which are at best only moderately palatable. Shrubs are seldom encountered.

Changes with grazing.--The principal species that are likely to decrease with overgrazing in this habitat type are *Deschampsia caespitosa, Agropyron caninum, Phleum alpinum*, and *Festuca idahoensis*. Principal species that will probably increase are *Danthonis intermedia, Potentilla diversifolia, Geum triflorum*, and *Polygonum bistortoides* h.t. The response of other species to overgrazing in the *Festuca idahoensis* series is covered in the discussion of the *FEID/AGSP* h.t.

Range management.--Since this type occurs only at high elevations, livestock use is restricted to a relatively short summer grazing season. The type appears equally suited for cattle and sheep. Usually the type is restricted by topo-edaphic conditions at these high elevations and does not cover very large areas. Grazing influences on the type have not been studied.

Deschampsia caespitosa / Carex spp. h.t.

(*DECA/CAREX* h.t.)

Distribution and environment.--The *DECA/CAREX* h.t. is a distinct meadow type found on poorly drained, high elevation valley bottoms and other flat areas commonly flooded by late spring and early summer snow melt. We encountered this type (fig. 14) on both sides of the Continental Divide, usually at elevations between 6,000 and 9,000 ft (1,800 and 2,700 m). The soils are usually deep and poorly drained, with water standing on the soil surface at least during the early part of the growing season. The soil surface is ordinarily completely covered by vegetation and litter. This is considered the most moist mountain grassland habitat type occurring in western Montana.

Figure 14.--*Deschampsia caespitosa/Carex* spp. h.t. west of Whitefish in northwestern Montana. This type frequently occupies mountain meadows with poorly drained soils.

Vegetative composition.--*Deschampsia caespitosa* is always abundant in this type. Other species are not consistently present, although one or more members of the *Carex* genera are always present. *Danthonia intermedia, Phleum alpinum*, and species of *Agrostis* and *Juncus* are usually present. *Agropyron* and *Festuca* species are conspicuously absent. The most commonly occurring forbs are *Potentilla gracilis, Antennaria corymbosa*, and *Polygonum bistortoides* (appendix E5).

Productivity.--The *DECA/CAREX* meadows are potentially the most productive grasslands in western Montana. Ample soil moisture available during a good part of the growing season and relatively deep soils contribute to lush growth. We measured production on only one stand in this type and obtained 2,595 lb/acre (2,906 kg/ha) dry matter. Ninety-nine percent of this consisted of graminoids, of which 26 percent was *Deschampsia caespitosa* and 56 percent was various species of *Carex*. Canopy cover from 6 stands (appendix E5) suggests that most meadows have fewer sedges than this and more forbs. Judging from these data, about 50 percent of the production will usually consist of palatable grasses, about 30 percent of moderately palatable sedges and rushes, and about 20 percent of a mixture of forbs generally low in palatability.

Changes with grazing.--Although our basis for judging species reaction to grazing in the *DECA/CAREX* h.t. is poor, certain changes are likely. The principal species that will probably decrease with heavy grazing are *Deschampsia caespitosa, Phleum alpinum,* and *Agrostis* spp. Those that will probably increase are *Juncus* spp., *Danthonia intermedia, Antennaria corymbosa, Achillea millefolium, Polygonum bistortoides,* and *Potentilla diversifolia*. Both *Poa pratensis* and *Taraxicum officinale* are probable invaders. The various species of *Carex* will very likely tend to increase.

Range management.--These meadows are among the best summer range in western Montana for cattle. Suitability for sheep is not as great because of the predominantly graminoid vegetation. Although the meadows may be accessible to livestock fairly early in the summer, use should be discouraged until the soils are no longer saturated with water. Pickford and Reid (1942) indicate that use of such meadows before the soils are firm enough to withstand trampling can be very damaging. Since both elk and deer commonly frequent these lush mountain meadows, care must be taken to avoid use conflicts between livestock and wildlife.

From studies of similar meadows in eastern Oregon and Washington, Reid and Pickford (1946) concluded that proper use of *Deschampsia caespitosa* can be as high as 55 percent, and the associated forage species can be utilized to about 50 percent. Pond (1961) observed that clipping similar mountain meadows in northern Wyoming to a 3-in (7.6-cm) height every 2 weeks harmed production but not plant density. More intensive clipping reduced density as well. However, he observed that clipping to a 1-in (2.5-cm) height at the end of the growing season had little effect on the native meadow plants.

The condition classes of *Deschampsia caespitosa* series meadows in eastern Oregon and Washington described by Reid and Pickford (1946) may be generally appropriate for our western Montana meadows as well. They indicate that good to excellent condition is typified by a dense stand of *Deschampsia caespitosa*. Condition is only fair when this dominant grass becomes patchy and interspersed with areas of such showy forbs as *Senecio* spp., *Erigeron speciosus*, and *Potentilla arguta*. The drier, better-drained portions of the meadows decline most rapidly. On moderately dry sites, *Poa pratensis* and *Agrostis* spp. begin to increase as conditions decline. *Koeleria cristata, Danthonia intermedia,* and *Bromus* spp. increase on the driest sites. On poor condition meadows, *Deschampsia caespitosa* is found only as small patches. The wet areas are dominated by *Carex* spp. and *Juncus* spp. and the drier sites by a cover of such forbs as *Antennaria corymbosa, Potentilla diversifolia, Agoseris glauca,* and *Gentiana affinis*.

Most often, range habitat types in mountainous topography are not large enough to be managed as single units. The use of any one type, therefore, must be coordinated with requirements of adjacent types included within the allotment pasture. The *DECA/CAREX* h.t. can be a management problem as well as a useful grazing indicator in such situations. Cattle tend to concentrate on and graze these meadows heavily before moving out to drier types (Smith and others 1967). Consequently, the meadow bottoms are usually heavily grazed before the adjacent slopes are grazed appreciably.

veruse and trampling of the meadow bottoms frequently causes stream erosion and hanneling. This in turn lowers the water table, alters soil moisture relations, and educes productivity. Pickford and Reid (1942) indicate that rotation and deferment s essential for maintaining productivity of such meadows. When a meadow is large nough, the potential productivity may warrant dividing the meadow into separate astures for intensive management. Not including adjacent slopes of widely different egetation and topography in the pasture would simplify overall management.

Noted elsewhere.--Mountain meadows dominated by *Deschampsia caespitosa* and various pecies of *Carex* are scattered throughout the northwestern states. They are physiognom- cally similar, have *Deschampsia caespitosa* as a major dominant, and share many genera. ther species, however, differ between various geographical areas.

Schlatterer (1972) described a tufted hairgrass meadow community for central daho dominated by *Deschampsia caespitosa* with *Carex praegracilis*, *Carex* spp., *Agrostis cabra*, and *Trifolium* spp. as associates. In eastern Oregon, Hall (1973) recognized a oist meadow community type dominated by *Deschampsia caespitosa* with *Carex microptera*, *grostis* spp., *Poa pratensis*, and *Danthonia californica* as major associates. Volland 1976) described a moist hairgrass meadow community type for central Oregon dominated y *Deschampsia caespitosa*, with *Carex pachystachya*, *Carex nebraskensis*, *Juncus balticus*, *alamagrostis canadensis*, and *Aster occidentalis* as major associates.

***Artemisia arbuscula* /*Agropyron spicatum* h.t.**

(*ARAR/AGSP* h.t.)

Distribution and environment.--The *ARAR/AGSP* h.t. is one of the driest mountain hrubland types occurring in western Montana. Communities of this type are found rimarily on foothill areas east of the Divide and south of 47° latitude. Usually hey occur on southerly and westerly exposures, on slopes as steep as 37 percent, and t elevations between 4,500 and 7,700 ft (1,400 and 2,300 m). The soils are commonly ry and rocky, with large amounts of bare soil and surface rock (appendix D).

Vegetative composition.--Morris and others (1976) indicate that both *Artemisia rbuscula* and *Artemisia nova* occur in southwestern Montana, with the latter probably eing most widely distributed. However, since Hitchcock and others (1955-69) treat *rtemisia nova* as a variety of *Artemisia arbuscula*, we did not attempt to separate his variety in the field. Both have been lumped into the *ARAR/AGSP* h.t. Refinement f the classification may well necessitate recognition of a separate habitat type ccupied by *Artemisia nova*. *Artemisia arbuscula* alone or in combination with *Artemisia ridentata* create the shrubby aspect in this shrubland type. *Agropyron spicatum* is he dominant herbaceous species; *Koeleria cristata* and *Poa sandbergii* are other constant rasses. Forbs are not abundant (2 to 20 percent canopy cover). Although a variety of orbs may occur, only *Phlox hoodii* and *Linum perenne* are usually constant. *Opuntia olyacantha* is the most common low-growing shrub (appendix E6). On the deeper soils in his type, *Artemisia tridentata* is usually associated with and may be even more abundant han *Artemisia arbuscula*. *Phlox hoodii* may also be more prominent on these heavy soils.

The *Stipa comata* phase (*STCO*) delineates the sandier soil areas where *Stipa comata* s conspicuous. *Oryzopsis hymenoides* is a frequent associate on these areas, as are *utierrezia sarothrae* and *Artemisia frigida*.

Productivity.--Our information on production in this type is sketchy. Harner and Harper (1975) found total production of somewhat similar vegetation in Utah to be 970 lb/acre (1,086 kg/ha), of which 360 lb/acre (403 kg/ha) were graminoids and 120 lb/acre (134 kg/ha) were forbs. This amount of herbaceous understory to the *Artemisia* corresponds well with the 411 lb/acre (460 kg/ha) reported by Hall (1973) for a low sagebrush--bunchgrass type in eastern Oregon similar to our *ARAR/FEID* h.t. Schlatterer (1972) indicates that total "forage" production in the *ARAR/AGSP* h.t. in central Idaho probably averages between 100 and 300 lb/acre (112 and 336 kg/ha). In Montana we can reasonably expect this type to produce a total of 400 to 800 lb/acre (448 to 896 kg/ha) of which half is shrubs and half is herbaceous. The shrubs are primarily *Artemisia arbuscula* and *Artemisia tridentata*. Judging from our canopy-cover data (appendix E6), approximately two-thirds of the herbaceous understory will consist of palatable grasses, primarily *Agropyron spicatum* and *Koeleria cristata*, and one-third of forbs relatively low in palatability.

Changes with grazing.--Overgrazing in the *ARAR/AGSP* h.t. probably will result in a decrease in the abundance of *Agropyron spicatum, Oryzopsis hymenoides, Eurotia lanata*, and possibly *Stipa comata* and *Koeleria cristata*. The principal species that will increase are *Gutierrezia sarothrae, Artemisia frigida, Bouteloua gracilis*, and possibly *Poa sandbergii*. Both *Artemisia tridentata* and *Artemisia arbuscula* tend to increase; if the area is badly overgrazed, *Artemisia arbuscula* will start to decrease. An indication of the reaction of other species within this type to heavy grazing can be obtained from the discussion of grazing within the *Stipa comata* and *Agropyron spicatum* series.

Range management.--This relatively low elevation shrubland type perhaps has greatest value as early spring and late fall cattle range. The presence of the *Artemisia arbuscula* shrub layer enhances the type's value for wildlife, particularly as deer winter range and as cover for sagegrouse. The sagebrush also complicates management because it competes with the desirable forage grasses for moisture and nutrients. Sagebrush increases with abusive cattle grazing to the detriment of forage production. However, the presence of *Artemisia arbuscula* can be a definite asset when the grasses are covered by snow; at such times it is fairly palatable and quite nutritious (Beetle 1960), particularly to sheep and deer.

Management considerations for the primary forage grasses are discussed in the *AGSP/BOGR* h.t. section. Control measures for sagebrush are discussed in the *ARTR/AGSP* h.t. section. *Artemisia arbuscula* and *Artemisia tridentata* are expected to react similarly to burning and spraying.

Noted elsewhere.--Vegetation dominated by *Artemisia arbuscula* with a predominantly *Agropyron spicatum* understory occurs on arid sites in Idaho, Oregon, and Nevada as well as in Montana. Franklin and Dyrness (1969) described an *Artemisia arbuscula-Agropyron spicatum* association that occurs on shallow, stony soils in eastern Oregon. Schlatterer (1972) found a similar type in Idaho that occurs on shallow or gravelly soils with a restricted B-horizon. *Stipa thurburiana* was a common associate in this type rather than the *Stipa comata* found in the Montana type. Hironaka (1977) also observed this habitat type in southern Idaho. Zamora and Tueller (1973) and Lewis (1975) described an *ARAR/AGSP* h.t. in northern Nevada that contains the same dominants as the Montana type, but differs in associated species. For example, the Nevada type does not contain *Gutierrezia sarothrae, Opuntia polyacantha, Koeleria cristata*, or *Linum perene*, and contains *Phlox longifolia* instead of *Phlox hoodii*.

Artemisia arbuscula/Festuca idahoensis h.t.

(*ARAR/FEID* h.t.)

Distribution and environment.--The *ARAR/FEID* h.t. is an infrequent type observed n the southwestern corner of Montana. It is generally found at higher elevations and nder less xeric conditions than the *ARAR/AGSP* h.t. It has been found on dry mountain lopes at elevations as high as 9,100 ft (2,800 m) and as low as 6,200 ft (1,900 m). ommunities of this type extend into Yellowstone National Park and environs and into djacent areas of Idaho.

Vegetative composition.--The *ARAR/FEID* h.t. differs vegetatively from the *ARAR/AGSP* .t. by the conspicuous amounts of *Festuca idahoensis* and the abundance of forbs (fig. 5). *Artemisia arbuscula* is the dominant shrub. In the higher elevation communities he *Artemisia arbuscula* may be ssp. *thermopola*. The predominant graminoids are *Festuca dahoensis, Agropyron spicatum*, and *Koeleria cristata*. The most common forbs are *ntennaria rosea, Phlox hoodii*, and *Erigeron compositus* (appendix E6).

igure 15.--*Artemisia arbuscula/Festuca idahoensis* h.t. on a north slope at 6,200 ft elevation near Gardner in southwestern Montana.

Productivity.--The *ARAR/FEID* h.t. is slightly more productive than the *ARAR/AGSP* .t. because it occurs on less arid sites. Hall (1973) reports that a similar type in astern Oregon produced 411 lb/acre (460 kg/ha) of grasses and forbs. Schlatterer 1972) suggests that the *ARAR/FEID* h.t. in central Idaho will produce up to 400 lb/acre 448 kg/ha). Total production for the *ARAR/FEID* h.t. in northern Nevada is reported o be about 400 to 500 lb/acre (448 to 560 kg/ha) of which 35 to 50 percent is sagebrush Lewis 1975). Although we did not measure productivity of the type in Montana, we elieve it should produce between 500 and 900 lb/acre (560 and 1,008 kg/ha) of total egetation, about half of which is palatable grasses, a fourth shrubs (primarily *rtemisia arbuscula*), and about a fourth a variety of forbs of relatively low palata- ility.

Changes with grazing.--A decrease in the principal forage producers, *Agropyron spicatum* and *Festuca idahoensis*, can be expected with overgrazing in this habitat type. *Artemisia frigida, Poa sandbergii,* and *Phlox hoodii*, along with the shrub *Artemisia arbuscula*, will be the principal species that increase. *Artemisia arbuscula* is a fairly palatable sagebrush that may decrease under continued heavy use. Very likely *Koeleria cristata* and *Antennaria rosea* will also increase with grazing. An indication of the reaction of other species in this type to grazing can be obtained from the discussion of grazing effects in the *Agropyron spicatum* and *Festuca idahoensis* series.

Range management.--Since this type generally occurs at higher elevations than the *ARAR/AGSP* h.t., use is usually restricted to late spring, summer, and early fall. The highest elevation areas are usually accessible only in summer. The type is probably equally suited for use by cattle or sheep.

Management considerations related to the primary forage grasses, *Festuca idahoensis* and *Agropyron spicatum*, are discussed in the *FEID/AGSP* and *AGSP/BOGR* h.t. sections. Although *Artemisia arbuscula* is generally more palatable than *Artemisia tridentata* (Beetle 1960), control of this shrub may occasionally be desired. Sagebrush control is discussed in the *ARTR/AGSP* h.t. section. *Artemisia arbuscula* will respond similarly to *Artemisia tridentata* to direct control efforts, but very likely such control will not be economically acceptable.

Noted elsewhere.--Franklin and Dyrness (1969) and Hall (1973) describe communities dominated by *Artemisia arbuscula* and *Festuca idahoensis* in eastern Oregon. These Oregon communities also have a number of secondary species in common with the Montana *ARAR/FEID* h.t., e.g., *Agropyron spicatum, Poa sandbergii, Phlox hoodii,* and *Phlox longifolia*. Hironaka (1977) and Schlatterer (1972) reported similar communities in central Idaho occurring on shallow-soiled, flat benches up to elevations of 8,000 ft (2,400 m). Communities dominated by *Artemisia arbuscula* and *Festuca idahoensis* also occur in northern Nevada, but the secondary species differ appreciably from those in the Montana communities (Lewis 1975; Zamora and Tueller 1973).

Artemisia tridentata /Agropyron spicatum (MONT) h.t.

(ARTR/AGSP h.t.)

Distribution and environment.--Although the *ARTR/AGSP* h.t. (fig. 16) does not appear to be restricted geographically, we encountered it primarily in the southwest quarter of the State. The type occurs on various exposures, on slopes up to 54 percent, and at elevations from 4,000 to 6,000 ft (1,200 to 1,800 m). It is found on shallow to moderately deep soils formed from a variety of parent materials. Even under good range conditions considerable rock (average 32 percent) and bare soil (average 11 percent) are present on the soil surface. Very likely this moderately arid type is restricted primarily to the 12- to 18-in (30- to 46-cm) precipitation zone.

Vegetative composition.--*Artemisia tridentata* is the obvious dominant shrub in this type, with a canopy cover averaging 15 percent. Although subspecies of *Artemisia tridentata* were not differentiated in the field phases of our study, *Artemisia tridentata* ssp. *wyomingensis* and the low elevation form of *Artemisia tridentata* ssp. *vaseyana* (Morris and others 1976) are believed to prevail in this habitat type in Montana. *Artemisia tridentata* ssp. *tridentata* may be found occupying the deeper soils in swales and sandy drainage ways. Low shrubs, particularly *Artemisia frigida* and *Gutierrezia sarothrae*, are usually present. The herbaceous understory is dominated by *Agropyron spicatum*; other usually conspicuous grasses are *Koeleria cristata, Poa sandbergii,*

igure 16.--*Artemisia tridentata/Agropyron spicatum* h.t. at 4,800 ft elevation in the Limestone Hills west of Townsend, Montana.

tipa comata, and *Bouteloua gracilis* (appendix E7). Though a variety of forbs may be resent, they generally are not abundant (1 to 18 percent canopy cover). No single orb species occurs consistently.

Productivity.--We measured production over a 3-year period on three relatively ndisturbed sites within this habitat type. The sites were selected to span the range n site potential. Differences in total annual production between sites did not xceed 15 percent, and differences between years attributable to weather did not xceed 25 percent. However, differences between sites and between years for vegetation lasses were considerably greater. Half again as much total grass and over four times s much total forbs were produced in one stand than in another. Shrub production was ighest where either grass or forb production was low. Over the 3-year period, almost wice as much grass was produced in the high year as in the low year. The extremes in otal production between stands and a measure of variability between years are presented n table 10.

able 10.--*Extremes in production and variability over a 3-year period in the* Artemisia tridentata/Agropyron spicatum *habitat type*

	Stand 8		Stand 239	
rowth form	Average	SE[1]	Average	SE[1]
	Air-dry lb/acre[2]			
raminoids	278	48	427	40
orbs	133	16	231	11
hrubs	328	37	206	16
Total	739	71	864	43

[1]Standard error over 3-year period.
[2]Multiply by 1.12 for kg/ha.

In similar vegetation in eastern Washington where *Artemisia tridentata* spp. *tridentata* is a dominant, Daubenmire (1970) found total production on long ungrazed and unburned sites to be 640 to 1,023 lb/acre (717 to 1,146 kg/ha); between 44 and 60 percent of this consisted of perennial grasses. Two ungrazed *Artemisia tridentata/Agropyron spicatum* communities in southern Idaho (Passey and Hugie 1963) produced only 337 and 682 lb/acre (388 and 764 kg/ha), of which approximately 50 percent was grass, 20 percent forbs, and 30 percent shrubs. Lewis (1975) found that the *Artemisia tridentata* ssp. *vaseyana/Agropyron spicatum* h.t. in northern Nevada produced between 600 and 1,000 lb/acre (672 and 1,120 kg/ha).

In the stands that we measured in western Montana, between 40 and 50 percent of the total production was grasses, 7 to 27 percent forbs, and the remainder was shrubs. *Agropyron spicatum* was the most important forage species, accounting for between 20 and 45 percent of the total vegetation production. *Koeleria cristata, Poa sandbergii,* and *Stipa comata* produce lesser amounts of forage. Although many species of forbs may be present, they do not contribute much to overall forage production because of low palatability. *Artemisia tridentata* usually accounts for more than 75 percent of the shrub production.

Changes with grazing.--Heavy grazing in this habitat type results primarily in a decrease of *Agropyron spicatum* and usually of *Stipa viridula*, although the latter grass appears to persist better than *Agropyron spicatum* under heavy use. Such palatabl forbs as *Balsamorhiza sagittata* and *Crepis acuminata* generally decrease when grazed heavily by sheep. Substantial increases can be expected in such grazing resistant grasses as *Bouteloua gracilis* and *Poa sandbergii*, and such unpalatable low shrubs as *Artemisia frigida, Gutierrezia sarothrae,* and *Opuntia polyacantha*. *Stipa comata* also may increase with excessive grazing, at least initially. The principal overstory shrub, *Artemisia tridentata*, is relatively unpalatable and usually increases readily as competition from the more palatable species is reduced. *Bromus tectorum* is usually the principal invader. The response of other species will probably be similar to the responses discussed for the *Agropyron spicatum* series.

Range management.--The *ARTR/AGSP* h.t. is best suited as early spring and late fall cattle range. It is less valuable for sheep because of the lack in abundance of forbs. Although *Artemisia tridentata* ssp. *tridentata* generally lacks palatability and is little used by livestock, ssp. *wyomingensis* is fairly palatable to both livestock and wildlife. Wildlife values may be high; depending upon location, the type is important winter range particularly for deer. Sagegrouse frequent the type as well.

Management considerations for the primary forage grass, *Agropyron spicatum*, are discussed in the *AGSP/BOGR* h.t. section. The usual abundance of *Artemisia tridentata* complicates management for the production of livestock forage. Decreased vigor of the palatable grasses and forbs inevitably results in an increase in the amount of this unpalatable shrub. Once established, *Artemisia tridentata* competes severely with the herbaceous understory and tends to suppress establishment of new grass plants (Blaisde 1949). Dense stands of sagebrush also impede livestock movement and forage availabili Consequently, sagebrush control measures may be required occasionally to reduce compet tion from this shrub and to improve overall forage production.

Of the many methods for controlling sagebrush (burning, spraying, railing, beatin cutting, plowing) burning and spraying are the most economically feasible. These two methods are used primarily where a good understory of perennial grasses and forbs exists and will be released by a reduction in sagebrush. A doubling or even tripling (Hyder and Sneva 1956; Wilbert 1963) of herbaceous production is not uncommon wherever sagebrush is controlled. Each method of control, however, has disadvantages as well as advantages. For example, burning not only effectively kills sagebrush but also temporarily weakens the grasses (Blaisdell 1953; Mueggler and Blaisdell 1958; Conrad and Poulton 1956). Spraying effectively kills sagebrush, but it tends to be detriment

o some forbs (Mueggler and Blaisdell 1958) and may temporarily affect wildlife alues adversely. Whereas burning usually removes most of the aboveground material, praying leaves standing dead shrubs, which continue to impede animal movement for everal years. This dead material, however, provides protection for the establishment f desirable grasses and forbs. Harniss and Murray (1973) found that the vegetation eturned to essentially preburn conditions after 30 years, even under good range anagement. Thilenius and Brown (1974) found that increased herbage production following praying for sagebrush control lasted only about 10 years. Where a good understory of erennial grasses and forbs do not exist, sagebrush control is ineffective unless ccompanied by seeding desirable forage species. Pechanec and others (1965) discuss n detail the conditions where sagebrush control may be warranted, the various methods f control, the relative advantages of each, and posttreanment management.

Care should be taken to insure that sagebrush control is compatible with wildlife alues. Both burning and spraying reduce brush cover and alter understory composition; his may be detrimental to some wildlife species. On the other hand, spraying sage-rush can be useful as a means of improving wildlife distribution. Wilbert (1963) ound that elk are attracted to sprayed areas in late spring.

Pechanec and Stewart (1949) recommend a rotation grazing system for *ARTR/AGSP* pring-fall range. Although their work relates specifically to sheep, a rotation razing system is also appropriate for cattle. It is important that the forage plants re not grazed year after year at a time in the spring when they are easily damaged. owever, heavy fall use, particularly by sheep, can benefit the range by reducing the mount of sagebrush (Laycock 1967). A rest-rotation grazing system may be appropriate here rough topography tends to hinder uniform forage utilization. Concentrating arge numbers of animals on an area for a limited period forces heavy but uniform use; est periods then permit the vegetation to recover from the heavy use.

The amount of available herbage that should be utilized can be considerably reater in the fall than in the spring, when the plants are more sensitive to abuse. or sheep grazing good-condition *ARTR/AGSP* range on gentle topography, Pechanec and tewart (1949) indicate that spring utilization of *Agropyron spicatum* should not xceed about 30 percent and *Stipa comata*, 50 percent. Fall utilization of these two pecies can be 45 and 70 percent, respectively. If the range is in only fair condition, tilization should be reduced approximately 10 percent.

Noted elsewhere.--Communities dominated by *Artemisia tridentata* and with *Agropyron picatum* as the dominant understory are widespread throughout the Northern Rocky ountains. Such communities have been described for southern British Columbia (Tisdale 947), Washington (Daubenmire 1970), Oregon (Franklin and Dyrness 1969), Idaho (Mueggler 950; Winward 1970; Schlatterer 1972; Hironaka 1977), Nevada (Lewis 1975), and Utah Christensen 1963).

Although the *ARTR/AGSP* h.t. described by Daubenmire (1970) for eastern Washington as the same dominants and some of the same secondary species as our Montana *ARTR/AGSP* .t., pronounced composition differences exist. The low shrubs *Artemisia frigida, utierrezia sarothrae*, and *Opuntia polyacantha*, and the grasses *Koeleria cristata* and *outeloua gracilis*, are usually conspicuous components in the Montana communities, but re lacking in the eastern Washington communities. Additional dissimilarities exist ith the forbs. The most meaningful similarities are the dominance of *Artemisia ridentata* and *Agropyron spicatum*, and the importance of *Stipa comata* and *Poa sandbergii* n the vegetation of both regions.

Winward (1970) partitioned the *ARTR/AGSP* h.t. in southeastern Idaho into two eparate types based primarily upon the subspecies of sagebrush that was present. His *rtemisia tridentata* ssp. *wyomingensis/Agropyron spicatum* h.t. lacked *Agropyron asystachyum*, had fewer forbs, and was generally more arid than his *Artemisia tridentata* sp. *vaseyana/Agropyron spicatum* h.t.

Artemisia tridentata/Festuca scabrella h.t.

(*ARTR/FESC* h.t.)

Distribution and environment.--The *ARTR/FESC* h.t. (fig. 17) occurs on both sides of the Continental Divide, but generally north of 46° latitude. It is usually found on southerly exposures with less than 30 percent slope at elevations between 3,800 and 6,000 ft (1,200 and 1,800 m). The soils are derived from various parent materials, and are usually moderately deep. Surface rock averages 16 percent and bare soil 4 percent. The type appears to occupy a rather broad precipitation zone, probably between 15 to 30 in (40 to 75 cm). In this respect, the *ARTR/FESC* h.t. might be considered the northwestern Montana equivalent of the *ARTR/AGSP* and *ARTR/FEID* habitat types, which are found primarily in the southwestern portion of the State.

Figure 17.--*Artemisia tridentata/Festuca scabrella* h.t. in the Copper Creek Exclosures, 5,900 ft elevation, north of White Sulphur Springs, Montana.

Vegetative composition.--This habitat type is characterized by the association of *Festuca scabrella* with *Artemisia tridentata*. Both *Artemisia tridentata* ssp. *wyomingensis* and ssp. *vaseyana* are probably associated with *Festuca scabrella*, with the latter dominant at the upper elevations of the habitat type. *Agropyron spicatum* and *Festuca idahoensis* are usually present and constitute a substantial portion of the herbaceous understory. Forbs are more abundant and varied here than in the *ARTR/AGSP* h.t. (appendix D). Generally, the most consistently occurring and abundant forbs are *Antennaria rosea*, *Arenaria congesta*, *Achillea millefolium*, *Eriogonum umbellatum*, and *Cerastium arvense* (appendix E7). Shrubs other than *Artemisia tridentata* are usually scarce.

Productivity.--Total annual production of vegetation in this habitat type appears comparable to that in the *FESC/FEID* h.t., between 1,100 and 1,600 lb/acre (1,232 and 1,792 kg/ha), but the proportion of usable forage is less. Judging from our canopy-cover data (appendix E7), only a little more than 50 percent of the total biomass consists of palatable grasses in contrast to more than 70 percent in the *FESC/FEID* h.t. The most productive forage species are *Festuca scabrella*, *Festuca idahoensis*, and *Agropyron spicatum*. A variety of forbs of questionable palatability comprise about 25 percent of the total biomass, and *Artemisia tridentata* about 20 percent.

Changes with grazing.--The most apparent and likely changes with overgrazing of is habitat type will be a decrease in the palatable grasses *Festuca scabrella* and *ropyron spicatum*, and subsequent increase in the principal shrub *Artemisia tridentata.* e other common grasses, *Festuca idahoensis, Poa cusickii,* and *Koeleria cristata* may so increase initially but these species will decrease also if heavy grazing persists. e principal herbaceous species that probably increase with overuse are *Cerastium vense, Achillea millefolium, Arenaria congesta, Antennaria rosea,* and *Phlox hoodii.* e response of other species to grazing will very likely be similar to their response the *Festuca scabrella* series.

Range management.--Management of the *ARTR/FESC* h.t. should be keyed primarily to e requirements of the most abundant forage grasses, *Festuca scabrella, Festuca ahoensis*, and *Agropyron spicatum.* The relative abundance of these grasses will ffer with specific sites, and management must be tailored to the existing conditions. quirements of the primary forage species are discussed in the *AGSP/BOGR, FESC/AGSP,* d *FEID/AGSP* h.t. sections. The occurrence of *Artemisia tridentata* complicates nagement, for it is a strong competitor that usually increases appreciably when the nge is overgrazed. Control of *Artemisia tridentata* is discussed in the *ARTR/AGSP* t. section.

Artemisia tridentata/Festuca idahoensis **(MONT) h.t.**

(*ARTR/FEID* h.t.)

Distribution and environment.--This habitat type (fig. 18) is found almost exclus-ely south of 46°30' latitude in western Montana. In the northwestern quarter of the ate, *Festuca scabrella* becomes a major co-dominant with *Artemisia tridentata* and places *Festuca idahoensis* as the characteristic associate. The *ARTR/FEID* h.t. curs at elevations ranging from 6,000 to 8,000 ft (1,800 to 2,400 m) on mountain opes with usually less than 40 percent slope. This is a moderately mesic shrubland pe that probably falls within the 16- to 30-in (40- to 75-cm) precipitation zone. e *Geranium viscosissimum* phase (*GEVI*) of the type is found generally at the upper rt of the precipitation zone on northerly and easterly exposures and at elevations ove 7,000 ft (2,100 m).

Soils from representative stands in the *ARTR/FEID* h.t. were classified as Typic yoboroll and Pachic Cryoboroll, with ustic moisture and cryic temperature regimens unn and others 1978). Solum thickness ranged from 16 to 33 in (41 to 84 cm), with to 21-in (10- to 54-cm) A horizons. Depth of free calcium carbonate ranged from to 40 in (41 to 102 cm). Solums were slightly acid to neutral in reaction. rmally, the soil surface is well covered with vegetation and litter (appendix D). e *Geranium viscosissimum* phase generally occupies the deeper soils.

Vegetative composition.--Although both *Artemisia tridentata* ssp. *wyomingensis* and p. *vaseyana* probably occur within this habitat type, the latter is by far the most mmon dominant shrub. The type is characterized by the presence of *Festuca idahoensis* the dominant grass understory, and by the absence of *Festuca scabrella. Agropyron icatum* and *Koeleria cristata* are constantly associated with *Festuca idahoensis.* Forbs, pecially *Geum triflorum,* are fairly abundant. The drier portion of this habitat pe is likely to contain such shrubs as *Chrysothamnus* spp. and *Artemisia frigida* minor associates.

Figure 18.--*Artemisia tridentata/Festuca idahoensis* h.t. on the Cliff Lake Research Natural Area, 7,200 ft elevation, in Madison county, Montana. The scattered, multi-aged populations of sagebrush has an abundant understory of grasses and forbs.

The more mesic portion of the type, the *Geranium viscosissimum* phase, is differentiated compositionally by a greater variety of graminoids and abundance of forbs as understory to the prevalent *Artemisia tridentata* overstory. The presence and often abundance of such graminoids as *Danthonia intermedia*, *Bromus carinatus*, *Agropyron caninum*, *Stipa occidentalis*, and *Carex raynoldsii*, as well as such forbs as *Geranium viscosissimum*, *Potentilla gracilis*, *Potentilla arguta*, *Helianthella uniflora*, and *Erigonum umbellatum* characterize this phase (appendix E7).

Productivity.--This type produces considerably more vegetation than the *ARTR/AGSP* h.t. The range in productivity, however, is fairly wide--almost a twofold difference in yield was found between stands selected to span the range in site potential. We found that total production on the better sites (*Geranium viscosissimum* phase) is comparable to that in the *FEID/AGCA* h.t., whereas the less productive sites are more comparable in production to the *FEID/AGSP* h.t. At most, about a 50 percent difference in annual production occurred over a 3-year period because of weather differences. This was roughly the same as that found for the *FEID/AGSP* and *FEID/AGCA* habitat types, the shrubless equivalents of the *ARTR/FEID* h.t. Extremes in production between stands and a measure of variability over a 3-year period are presented in table 11.

Hall (1973) indicated that production of just grasses and forbs in similar vegetation in eastern Oregon is 412 lb/acre (461 kg/ha). Schlatterer (1972) reported that total production of the *ARTR/FEID* h.t. in the mountains of central Idaho is usually 500 to 700 lb/acre (560 to 784 kg/ha), but yields of more than 1,000 lb/acre (1,120 kg/ha) are possible. Wilbert (1963) measured yield on two western Wyoming sites similar to the *ARTR/FEID* h.t. These produced 682 to 1,728 lb/acre (764 to 1,935 kg/ha), of which about 20 to 30 percent was grass, 30 to 35 percent forbs, and 40 to 50 percent shrubs.

able 11.--*Extremes in production and variability over a 3-year period in the* Artemisia tridentata/Festuca idahoensis *habitat type*

Growth form	Stand 272		Stand 46	
	Average	SE[1]	Average	SE[1]
	Air-dry lb/acre[2]			
Graminoids	201	12	609	33
Forbs	423	84	691	53
Shrubs	139	27	144	27
Total	769	103	1,443	44

[1]Standard error over 3-year period.
[2]Multiply by 1.12 for kg/ha.

ueggler and Blaisdell (1958) indicate that similar vegetation in southeastern Idaho veraged 742 lb/acre (831 kg/ha) over 3 years. During this period, approximately 40 ercent more biomass was produced during the high year as during the low year. Approxi-ately 30 percent of this production consisted of graminoids, 10 percent forbs, and lmost 60 percent shrubs; sagebrush comprised almost 95 percent of the shrub produc-ion. Lewis (1975) reported production figures of 900 to 1,300 lb/acre (1,008 to 1,456 g/ha) for this type in northern Nevada.

In the Montana stands that we sampled for production, graminoids constituted 21 to 2 percent of the biomass, forbs 38 to 56 percent, and shrubs 10 to 41 percent. Most of he graminoid production consisted of palatable grasses; only in the *Geranium viscossimum* hase did an appreciable amount of sedges occur (appendix E7). Most of the forbs are ather poor forage, with the possible exceptions of *Helianthella uniflora, Geranium iscosissimum*, and *Potentilla arguta* which are found primarily in the *Geranium viscosi-simum* phase. Eighty-eight to 98 percent of the shrub production in these Montana tands was *Artemisia tridentata.*

Changes with grazing.--Overgrazing of the type will cause a reduction of such alatable species as *Agropyron spicatum* and *Festuca idahoensis.* The unpalatable shrubs, *rtemisia tridentata* and *Chrysothamnus viscidiflorus,* will tend to increase as will the npalatable forbs *Geum triflorum, Arenaria congesta,* and *Achillea millefolium.* In the *eranium viscosissimum* phase of the type, *Agropyron caninum, Bromus carinatus, Carex aynoldsii,* and possibly *Stipa occidentalis* also may decrease appreciably with heavy attle use. Continued heavy sheep use of this phase may cause a decrease in *Helianthella nifloria, Potentilla arguta, Geranium viscosissimum,* and possibly *Potentilla gracilis.* he reaction of other species to overuse will likely parallel the responses discussed or the *Festuca idahoensis* series.

Range management.--The *ARTR/FEID* h.t. is well suited as late spring to early fall ange for all classes of livestock. Use at the higher elevations, however, may be estricted to just the summer season because of late plant development and early fall nows. The *Geranium viscosissimum* phase is particularly well suited for sheep because f the rich complement of forbs. The type frequently is important wildlife habitat, specially for mule deer and sagegrouse.

A rest-rotation system of grazing is often preferred for the type because of the mountainous topography. Drainage bottoms usually receive heavy use while adjacent slopes are underused. The heavy, short-term stocking of a rest-rotation system combine with proper water development and fencing usually improves livestock distribution. Where topography is not a handicap, deferred rotation and season-long systems may suffice.

Many of the management considerations discussed in the *FEID/AGSP* and *FEID/AGCA* h.t sections are also applicable to the *ARTR/FEID* h.t. The abundance of *Artemisia tridenta* however, requires that consideration be given to control of this competitive shrub to improve forage production. Sagebrush control is discussed in the *ARTR/AGSP* h.t. sectio

Noted elsewhere.--Communities dominated by *Artemisia tridentata* where *Festuca idahoensis* is a conspicuous understory grass are fairly widespread. Tisdale and others (1965), Winward (1970), Schlatterer (1972), and Hironaka (1977) described such communities in Idaho, Franklin and Dyrness (1969) and Hall (1973) in eastern Oregon, Lewis (1975) in Nevada, and Daubenmire (1970) in eastern Washington. Undoubtedly such communities occur also in western Wyoming and possibly in Utah.

The *ARTR/FEID* h.t. described by Daubenmire (1970) for eastern Washington apparentl is dominated primarily by *Artemisia tridentata* ssp. *tridentata*, whereas *Artemisia tridentata* ssp. *vaseyana* is most common in the type in Montana. The Montana type also appears much richer in perennial herbs. This is particularly true for the *Geranium viscosissimum* phase which contains such grasses as *Agropyron caninum, Bromus carinatus, Danthonia intermedia, Stipa occidentalis, Poa juncifolia,* and *Koeleria cristata,* and such forbs as *Campanula rotundifolia, Geum triflorum, Geranium viscosissimum,* and *Potentilla gracilis*; these species are not listed for the type in Washington. In contrast, Daubenmire's *ARTR/FEID* h.t. contains a much greater diversity and abundance of annuals than the Montana type.

Winward (1970) found that *Festuca idahoensis* becomes a codominant species in southeastern Idaho at about 6,500 to 7,000 ft (1,981 to 2,134 m) elevation, with fingers extending to lower elevations on northeast facing slopes. He categorized this vegetation into two habitat types based upon the form of sagebrush present and upon different associated species. His *Artemisia tridentata vaseyana/Festuca idahoensis* h.t is comparable to our *ARTR/FEID* h.t. His *Artemisia tridentata vaseyana* form *spiciformis Bromus marginatus/Festuca idahoensis* h.t. generally occurs above 7,000 ft (2,134 m) on cool mesic sites. It appears somewhat comparable to our *Geranium viscosissimum* phase of the habitat type.

Artemisia tripartita/Festuca idahoensis (MONT) h.t.

(*ARTRI/FEID* h.t.)

Distribution and environment.--Stands dominated by *Artemisia tripartita* are very localized in Montana; examples of the *ARTRI/FEID* h.t. (fig. 19) were observed only in the extreme southwestern part of the State. Usually this habitat type occurs on gentle alluvial slopes or benches with moderately deep soils. Bare soil ranged from 1 to 11 percent and surface rock cover from 0 to 25 percent on the five stands of this type that we sampled. The environmental distinction between this habitat type and drier stands in the *ARTR/FEID* h.t. is unknown.

'igure 19.--*Artemisia tripartita/Festuca idahoensis* h.t. at 6,900 ft elevation near Dillon in southwestern Montana.

Vegetative composition.--This type is similar vegetatively to the drier portion ›f the *ARTR/FEID* h.t., except for the prevalent overstory of *Artemisia tripartita* ınd apparent association of *Calamagrostis montanensis* with *Festuca idahoensis* in the ınderstory. The shrubs *Chrysothamnus viscidiflorus, Tetradymia canescens,* and *.rtemisia frigida* are usually present. Although *Artemisia tridentata* may be present, t is not abundant. *Festuca idahoensis, Koeleria cristata,* and *Calamagrostis montanensis* re the principal graminoids; *Stipa comata, Agropyron spicatum,* and rhizomatous *Agro-yron* spp. may also be abundant in some cases. *Phlox hoodii, Antennaria rosea,* and *upinus sericeus* are the principal forbs (appendix E8).

Productivity.--We did not sample vegetation production in this type. Very likely, owever, it is similar to that of the drier part of the *ARTR/FEID* h.t.--about 800 to ,200 lb/acre (896 to 1,344 kg/ha). Both of these types have similar structure, a mixed rass-forb understory to a dominating *Artemisia* shrub layer, and occur in similar nvironmental situations. Daubenmire (1970) found production of a stand of similar egetation in eastern Washington to be 1,283 lb/acre (1,437 kg/ha), of which 85 percent as perennial grass. Schlatterer (1972) reports that production of the *ARTRI/FEID* h.t. n central Idaho ranges from 250 to 700 lb/acre (280 to 784 kg/ha), which seems very ow. Judging from our canopy-cover data (appendix E8), an average 69 percent of the iomass of Montana stands is palatable grass, 17 percent forbs of rather low palatability, nd 14 percent shrubs of low palatability. The proportion of grasses appears considerbly higher in the *ARTRI/FEID* h.t. than in the *ARTR/FEID* h.t.

Changes with grazing.--All of the shrubs within this habitat type are undesirable orage species and usually increase with heavy grazing. The most prominent of these are *rtemisia tripartita, Chrysothamnus viscidiflorus,* and *Tetradymia canescens*. The low hrubs, *Gutierrezia sarothrae* and *Artemisia frigida*, are also conspicuous increasers. s such palatable grasses as *Agropyron spicatum, Agropyron caninum,* and *Festuca idaho-nsis* decrease with overuse, *Calamagrostis rubescens, Agropyron dasystachyum,* and *eleria cristata* may tend to increase; however, these latter three grasses will decrease nder continued heavy use. *Achillea millefolium* and *Phlox hoodii* are generally the ost prominent forbs to increase. Response to grazing of other species found in this abitat type will probably be similar to their response to grazing discussed in the *estuca idahoensis* series.

Range management.--Management considerations relevant to maintenance of forage production in the *FEID/AGSP* h.t. are appropriate for this type as well. However, the dominance of *Artemisia tripartita* complicates management. This shrub is an aggressive competitor, is relatively unpalatable, and, in striking contrast to *Artemisia arbuscula* and *Artemisia tridentata*, sprouts readily from the stump (Beetle 1960). Consequently, burning is not an effective control measure for *Artemisia tripartita.* Even though fire kills back the tops, stump sprouts may rapidly restore the shrub to a dominant position in the community. Spraying herbicides may be at least partly effective in controlling this species (Blaisdell and Mueggler 1956b).

Noted elsewhere.--An *ATRI/FEID* h.t. was identified in southern Idaho by Hironaka (1977). Schlatterer (1972) described an *Artemisia tripartita--Festuca idahoensis* community for central Idaho that lacks the rhizomatous *Agropyron* spp. and *Calamagrostis montanensis* which are fairly common in the Montana type. The *ARTRI/FEID* h.t. described by Daubenmire (1970) for eastern Washington also lacks a number of perennial species that are often abundant in the Montana version of the type. Among the more conspicuous of these are the aforementioned rhizomatous grasses, *Phlox hoodii, Antennaria rosea,* and *Carex stenophylla.* On the other hand, *Carex filifolia, Phlox longifolia,* and many annuals are much more abundant in the Washington type than in the Montana type.

Potentilla fruticosa /Festuca scabrella h.t.

(*POFR/FESC* h.t.)

Distribution and environment.--The *POFR/FESC* h.t. is found only north of 46° latitude and primarily east of the Continental Divide. Usually it occurs on gently sloping or rolling topography at elevations between 4,500 and 6,000 ft (1,372 and 1,829 m). The soils are moderately deep, 10- to 18-in (25- to 45-cm) rooting depth, and usually of either limestone or sandstone parent materials. Considerable surface rock may be exposed, but usually very little bare soil is evident. Vegetation and litter cover commonly exceed 98 percent in the *Danthonia intermedia* phase (*DAIN*). This is a moderately mesic foothill type that probably falls within the 20- to 30-in (50- to 75-cm) precipitation zone. The *Danthonia intermedia* phase occurs where moisture relations are better than average.

Vegetative composition.--The typal shrub, *Potentilla fruticosa,* may not be readily visible in this habitat type because of the tall vigorous growth of *Festuca scabrella* (fig. 20). However, *Potentilla fruticosa* is not only present but has a canopy cover usually between 5 and 30 percent. *Festuca idahoensis* and *Koeleria cristata* are secondary grasses usually associated with the overwhelmingly dominant *Festuca scabrella.* Forbs frequently occur in great variety, the most prevalent being *Galium boreale, Gailardia aristata, Achillea millefolium, Solidago missouriensis,* and *Campanula rotundifolia* (appendix E9). On the drier sites, *Agropyron spicatum, Carex scirpoides, Artemisia frigida, Gutierrezia sarothrae, Chrysopsis villosa,* and *Senecio canus* are often conspicuous.

The *Danthonia intermedia* phase is typified by the presence of *Danthonia intermedia* in combination with the relative abundance of *Agropyron canium, Potentilla gracilis, Lupinus sericeus,* and *Carex obtusata.*

igure 20.--*Potentilla fruticosa/Festuca scabrella* h.t. ocurring where the plains meet the mountain, 4,340 ft elevation, near Dupuyer in northern Montana.

Productivity.--A large amount of variation in site potential and in yearly produc-ion exists in this habitat type. We found almost a twofold difference in total roduction between 3 stands selected to span the range in site potential. The *Danthonia ntermedia* phase appeared most productive. We also found a twofold difference in roduction over a 3-year period because of yearly weather differences. Production of oth the forb and shrub groups tended to be more variable than that of the grasses. he extremes in production between stands and a measure of variability between years re presented in table 12.

able 12.--*Extremes in production and variability over a 3-year period in the* Potentilla fruticosa/Festuca scabrella *habitat type*

Growth form	Stand 354		Stand 258	
	Average	SE[1]	Average	SE[1]
	Air-dry lb/acre[2]			
Graminoids	676	97	1,155	138
Forbs	194	58	436	93
Shrubs	50	12	169	64
Total	920	157	1,773	271

[1]Standard error over 3-year period.
[2]Multiply by 1.12 for kg/ha.

Usually almost 75 percent of the total vegetative biomass consists of palatable graminoids, about 20 percent forbs of questionable forage value, and less than 10 percent shrubs. *Festuca scabrella* ordinarily constitutes about two-thirds of the graminoid production. Other substantial forage producers may be the highly palatable *Agropyron caninum* and *Poa pratensis*, and the moderately palatable *Danthonia parryi* and *Danthonia intermedia* (appendix E9). Many different forbs may be present, but no single species appears to be a substantial producer of livestock forage. The shrubs produce little usable forage.

Changes with grazing.--*Potentilla fruticosa* fills a role in this series similar to *Artemisia tridentata* in its series. Both are shrubs unpalatable to livestock, and both will probably increase with overgrazing. Other prominent species in this habitat type that tend to increase with overuse are *Artemisia frigida, Danthonia parryi, Danthonia intermedia,* and such forbs as *Cerastium arvense, Achillea millefolium,* and *Campanula rotundifolia*. The palatable grasses, *Festuca scabrella, Agropyron caninum,* and *Agropyron spicatum,* generally decrease under heavy use. *Festuca idahoensis, Koeleria cristata,* and *Helictotrichon hookeri* tend to increase under moderate use, but will usually decrease under continued heavy grazing. Very likely the forbs *Lupinus sericeus, Gaillardia aristata, Galium boreale, Senecio canus,* and possibly *Potentilla gracilis* will decrease on heavily grazed sheep range, but increase on cattle range. Other species within this habitat type will likely respond to grazing as they do in the *Festuca idahoensis* series.

Range management.--Except for the presence of *Potentilla fruticosa*, this habitat type is similar to the grasslands in the *Festuca scabrella* series. It is probably better suited for grazing by cattle and horses than by sheep since large tussock grasses produce most of the forage. The type can be grazed in late spring, summer, and early fall. The principal forage species within this type are expected to react to grazing as they do in the *Festuca scabrella* series, and as discussed in the *FESC/AGSP* and *FESC/FEID* h.t. sections. However, *Potentilla fruticosa* will likely increase appreciably with overgrazing and complicate management. This shrub is normally not used to any extent by either livestock or big game. Appreciable use of the shrub usually is indicative of overgrazing, unless the range is on a rest-rotation management system. Although *Potentilla fruticosa* does not appear to be as aggressive as sagebrush, it is difficult to control for it sprouts readily following burning or spraying with 2,4-D.

***Potentilla fruticosa /Festuca idahoensis* h.t.**

(*POFR/FEID* h.t.)

Distribution and environment.--This is an uncommon habitat type (fig. 21) found at elevations between 6,500 and 8,600 ft (2,000 and 2,600 m) on the east side of the Continental Divide. It occurs primarily on gentle mountain slopes with moderately deep soils of granitic origin. Normally the soil surface is well covered with vegetation and litter. The type is considered moderately mesic, probably falling within the 20- to 30-in (50- to 75-cm) precipitation zone.

Vegetative composition.--Usually *Potentilla fruticosa* is the only shrubby species present. In some cases, however, *Artemisia tridentata* ssp. *vaseyana* or *Artemisia cana* are part of the community. *Festuca idahoensis* and *Danthonia intermedia* are the dominant graminoids; *Carex obtusata* may also be abundant. If present, *Festuca scabrella* and *Agropyron spicatum* are widely scattered. *Achillea millefolium, Besseya wyomingensis,* [illegible], *Campanula rotundifolia,* and *Potentilla gracilis* are the most common forbs (appendix E9). *Geum triflorum* is sometimes abundant.

Figure 21.--*Potentilla fruticosa/Festuca idahoensis* h.t. at 7,240 ft elevation on a north exposure near Big Timber in south central Montana.

Productivity.--We did not measure plant production in this habitat type. The overall similarity between this type and the *FEID/AGCA* h.t. in species composition (with the exception of *Potentilla fruticosa*) and in environment suggests that total production probably is between 1,200 and 1,500 lb/acre (1,344 and 1,680 kg/ha). Judging from our canopy-cover data (appendix E9), the unpalatable *Potentilla fruticosa* averages less than 10 percent of the vegetation. Approximately 35 percent of the total consists of a mixture of forbs of generally low palatability. About 60 percent of the total vegetation usually consists of palatable grasses and sedges, the most productive of which are *Festuca idahoensis* and *Danthonia intermedia*.

Changes with grazing.--The primary species that decrease with overgrazing in the *POFR/FEID* h.t. are *Agropyron caninum*, *Festuca idahoensis* and possibly *Carex obtusata*. Although the grasses *Koeleria cristata* and *Danthonia intermedia* may increase initially, they tend to decrease with continued heavy use. *Potentilla fruticosa*, the only shrub of consequence, generally increases appreciably as do such forbs as *Geum triflorum* and *Potentilla gracilis*. Other species within this type probably respond to grazing as they do in the *Festuca idahoensis* series.

Range management.--Grazing in this type is generally confined to summer months since it usually occurs above 6,500-ft (1,981-m) elevation. The type is about as well suited for cattle as it is for sheep. The herbaceous vegetation is expected to respond to grazing much as it does in the *FEID/AGCA* h.t. However, the presence of *Potentilla fruticosa* may complicate management. This shrub fills a role somewhat similar to that of *Artemisia tridentata* in the *ARTR/FEID* h.t.; it is a relatively unpalatable woody plant that tends to increase with overgrazing. Although it does not appear to compete as aggressively as *Artemisia tridentata*, it is more difficult to control because of its ability to sprout following burning or spraying.

Noted elsewhere.--A vegetative type similar to the *POFR/FEID* h.t. but with *Artemisia tridentata* and *Artemisia cana* intermixed with *Potentilla fruticosa* in the overstory has been observed in Hayden Valley, Yellowstone National Park (D. C. Graham, personal communication). The *POFR/FEID* h.t. has also been observed in northern Nevada, western Wyoming, and central Idaho (E. F. Schlatterer, personal communication).

Purshia tridentata/Agropyron spicatum **(MONT) h.t.**

(*PUTR/AGSP* h.t.)

Distribution and environment.--The *PUTR/AGSP* h.t. (fig. 22) occupies rather extensive foothill areas in the Bitterroot Valley. Elsewhere it ordinarily is found as small patches, less than 20 acres (8 ha), in rather specialized environments. The type was observed only west of the Continental Divide. It occupies rather steep (40 to 75 percent) predominately southerly exposures at elevations ranging from 3,500 to 5,500 ft (1,100 to 1,700 m). The soils of the stands we examined were dry, shallow, rocky, and predominately granitic in origin. Considerable rock and bare soil was exposed on the soil surface. This is a semiarid habitat type probably confined to the 10- to 15-in (25- to 40-cm) precipitation zone on sites with high evapotranspiration.

Figure 22.--*Purshia tridentata/Agropyron spicatum* h.t. in the Bitteroot Valley, elevation 4,200 ft, south of Darby. Usually this type does not occur in such extensive stands in Montana.

Vegetative composition.--The type is conspicuously dominated by *Purshia tridentata* which typically grows in somewhat open stands. Other medium-tall shrubs such as *Chrysothamnus nauseous* and *Chrysothamnus viscidiflorus* may be present, but seldom form a substantial part of the community. *Agropyron spicatum* is the predominant understory grass (appendix E10). *Koeleria cristata*, *Poa sandbergii*, and *Stipa comata* may also be present. Both *Festuca idahoensis* and *Festuca scabrella* are lacking. *Bromus tectorum* is usually a conspicuous annual grass within the *Purshia tridentata* series. *Balsamorhiza sagittata* is often a dominant forb. Other common forbs include *Chrysopsis villosa*, *Lupinus sericeus*, *Lithospermum ruderale*, *Tragopogon dubius*, and *Achillea millefolium*.

Productivity.--Total production of vegetation appears to be similar to that in the *ARTR/AGSP* h.t., or about 700 to 800 lb/acre (784 to 896 kg/ha). The amount of usable forage produced, however, probably exceeds that in the *ARTR/AGSP* h.t. because of a greater proportion of palatable species. The dominant shrub, *Purshia tridentata*, is a desirable browse species in contrast to the relatively unpalatable *Artemisia tridentata*. In addition, the palatable forb *Balsamorhiza sagittata* often occurs in abundance. *Agropyron spicatum* is the primary forage grass.

Changes with grazing.--Most species within this habitat type will respond to grazing as they do in the *Agropyron spicatum* series. We can expect *Agropyron spicatum* to be the major decreaser under heavy cattle and horse use, and *Balsamorhiza sagittata* to be the major species to decrease under heavy spring and early summer sheep use. *Chrysothamnus viscidiflorus* and *Artemisia frigida* usually increase with overgrazing, and *Bromus tectorum* will invade. In contrast to most shrubs, *Purshia tridentata* is palatable to all classes of livestock and especially to deer and elk in the fall and winter.

Range management.--Stands within the *Purshia tridentata* series occur primarily as scattered small patches on fairly steep slopes throughout the foothills of western Montana. These stands may be adjacent to or interspersed with ponderosa pine and Douglas-fir forests. *Purshia tridentata* is a key browse for big game; consequently, such stands may be very important winter range for deer and elk. Since *Purshia tridentata* is palatable to both cattle and sheep, livestock use of these areas should be permitted only if not in conflict with use by wildlife.

McConnell and Garrison (1966) found that summer utilization of *Purshia tridentata* is more detrimental than the same amount of winter use because carbohydrate reserves are at a low from May through July. Part of the energy demands by the tops as well as by the roots are drawn from root reserves in early to middle summer. McConnell and Smith (1977) determined that late summer and fall use is considerably less detrimental than spring and early summer use. Apparently summer browsing should be minimized if the resource manager wishes to maintain good productivity and reproduction of this shrub for wildlife use in winter.

Browse production appears to be stimulated when the shrubs are utilized to a moderate degree in the fall or winter. Garrison (1953) observed that clipping from 50 to 75 percent of the current growth of *Purshia tridentata* at this time caused greater twig growth the following year than if the shrubs were not clipped. He also found, however, that heavy clipping year after year eventually caused a decline in shrub vitality. McConnell and Smith (1977) observed that the longevity of this valuable browse species was reduced by heavy utilization. Garrison (1953) recommended that to sustain production of *Purshia tridentata* winter use on good sites should not exceed 60 to 65 percent and on poor sites 50 percent of the current growth.

Burning can be very detrimental to *Purshia tridentata* (Wright 1971). Even though sprouting may occur (Blaisdell and Mueggler 1956a), particularly if the soils are wet at the time of burning or shortly thereafter, recovery may take 10 years or longer (Blaisdell 1953). *Purshia tridentata* is also severely injured by spraying with herbicides (Mueggler and Blaisdell 1958). Therefore considerable care should be exercised to avoid patches of *Purshia tridentata* where sagebrush control is part of the management strategy.

The understory species in the *PUTR/AGSP* h.t. are expected to respond to livestock use much as they do in the *ARTR/AGSP* h.t. The key species for spring-summer-fall grazing by cattle in this type is *Agropyron spicatum*. Management considerations for this major forage producer are discussed in the *AGSP/BOGR* h.t. section.

Noted elsewhere.--Daubenmire (1970) described a *PUTR/AGSP* h.t. that occurs only as scattered fragments in eastern Washington. The most notable species differences are the presence of *Artemisia frigida* and *Chrysopsis villosa* in the Montana type but not in the Washington type and the frequent lack of *Eriogonum* spp. which are common in the Washington type.

Purshia tridentata/*Festuca scabrella* h.t.

(*PUTR/FESC* h.t.)

Distribution and environment.--The *PUTR/FESC* h.t. occurs principally west of the Continental Divide and north of 47° latitude. The type appears topographically specific, as are the other habitat types within the *Purshia tridentata* series. It was observed in small patches on steep (more than 35 percent) southerly and easterly facing slopes, at elevations ranging from 3,000 to 5,000 ft (900 to 1,500 m). The type is fairly arid, probably falling within the 12- to 20-in (30- to 50-cm) precipitation zone.

Vegetative composition.--The *Purshia tridentata* understory is predominated by grasses (fig. 23). Although *Agropyron spicatum* and *Festuca idahoensis* may be the most prevalent species, *Festuca scabrella* is a conspicuous and often abundant associate. *Poa sandbergii* and *Koeleria cristata* also are usually present. The annual grasses, *Bromus tectorum* and *Festuca octoflora*, comprise a conspicuous part of the understory. *Balsamorhiza sagittata* is commonly an abundant forb, with *Achillea millefolium*, *Tragopogon dubius*, *Collinsia parviflora*, and *Lithosperum ruderale* frequent associates.

Figure 23.--*Purshia tridentata/Festuca scabrella* h.t. on a moderately steep southwest slope west of Flathead Lake in northwestern Montana.

Productivity.--We selected two stands within this habitat type to sample the range in site productivity. The good site produced about a third more total vegetation than the relatively poor site. Differences in production attributable to weather over a 3-year period amounted to almost 80 percent on the good site and more than 140 percent on the poor site. Average production over a 3-year period and a measure of yearly variability attributable to weather are presented in table 13.

able 13.--*Extremes in production and variability over a 3-year period in the* Purshia tridentata/Festuca scabrella *habitat type*

rowth form	Stand 246 Average	Stand 246 SE[1]	Stand 306 Average	Stand 306 SE[1]
	Air-dry lb/acre[2]			
raminoids	407	114	431	41
orbs	379	89	542	146
hrubs	110	52	239	91
Total	897	251	1,212	200

[1]Standard error over a 3-year period.
[2]Multiply by 1.12 for kg/ha.

Shrubs, primarily the desirable browse *Purshia tridentata*, generally comprise ess than 20 percent of the total annual vegetative production. Grasses and forbs form he remainder in about equal amounts. About two-thirds of the total forb production onsists of *Balsamorhiza sagittata*, a desirable forage plant; the remainder of the orbs are of questionable forage value. The primary forage grasses are *Agropyron picatum, Festuca scabrella,* and *Festuca idahoensis*. Therefore, forage plants of at east moderate palatability make up as much as 90 percent of the total production.

Changes with grazing.--Festuca scabrella and *Agropyron spicatum* are the principal rasses in this type that decrease under heavy summer use by cattle and horses. *estuca idahoensis, Koeleria cristata,* and *Poa sandbergii* may increase initially, but hey too will decrease with continued heavy use. Although *Balsamorhiza sagittata* may ncrease on cattle range, it decreases appreciably if heavily used by sheep in the pring and early summer. *Purshia tridentata* is a particularly desirable shrub on big ame winter range. It is also palatable to sheep and cattle. Repeated heavy use of his valuable browse will cause it to decline. *Bromus tectorum* is the principal pecies to invade. Other species within the type probably respond to grazing as they o in the *Festuca scabrella* series.

Range management.--As with the other habitat types within the *Purshia tridentata* eries, the greatest value of the *PUTR/FESC* h.t. often will be as big game winter ange. *Purshia tridentata* is the key browse species. Considerations related to its anagement are discussed in the *PUTR/AGSP* h.t. section. The understory vegetation is xpected to respond to livestock grazing much as it does in the *Festuca scabrella* eries. Key herbaceous species within the type are *Festuca scabrella, Agropyron picatum, Festuca idahoensis,* and *Balsamorhiza sagittata*. Requirements of these pecies are discussed in the *FESC/AGSP, AGSP/BOGR, AGSP/POSAN,* and *FEID/AGSP* h.t. ections.

***Purshia tridentata /Festuca idahoensis* (MONT) h.t.**

(*PUTR/FEID* h.t.)

Distribution and environment.--This habitat type (fig. 24) is seldom encountered n Montana. It may be found occasionally south of 47° latitude west of the Divide on teep southerly exposures where moisture conditions are adequate to support *Festuca dahoensis*. The shallow, rocky soils are usually granitic in origin. It has been bserved northeast of Deerlodge in small scattered patches at elevations above 5,000 ft 1,500 m).

Figure 24.--*Purshia tridentata/Festuca idahoensis* h.t. on a moderate steep southwest exposure northeast of Deer Lodge. The bitterbrush has been heavily browsed by deer in the winter.

Vegetative composition.--The *PUTR/FEID* h.t. is delineated from the *PUTR/AGSP* h.t. by the presence of *Festuca idahoensis*, and from the *PUTR/FESC* h.t. by the absence of *Festuca scabrella*. *Agropyron spicatum* is usually the dominant grass, but *Festuca idahoensis* is conspicuously present, along with *Koeleria cristata* and *Poa sandbergii*. *Arenaria congesta*, *Phlox hoodii*, *Eriogonum umbellatum*, and *Lupinus sericeus* are among the more abundant forbs.

Productivity.--Total vegetal production in the *PUTR/FEID* h.t. probably appraoches that in the *PUTR/FESC* h.t., or approximately 800 to 1,000 lb/acre (896 to 1,120 kg/ha). Perhaps as much as 75 percent of the production is composed of desirable forage specie: The primary forage grasses are *Agropyron spicatum*, *Festuca idhaoensis*, *Koeleria crista* and *Poa sandbergii*. The palatable *Purshia tridentata* is the primary shrub. The forbs are of questionable value as forage.

Changes with grazing.--The *PUTR/FEID* h.t. is particularly valuable as big game winter range, as are the other types within the *Purshia tridentata* series. *Purshia tridentata* is palatable to both big game and livestock. If used heavily and repeatedly it will decline in vigor. Heavy spring or summer use will cause *Agropyron spicatum*, *Festuca idahoensis*, and *Stipa viridula* to decline as well. *Poa sandbergii* and *Koeler cristata* may increase initially, but are likely to decrease with continued heavy use. Such unpalatable species as *Chrysopsis villosa*, *Artemisia frigida*, and *Phlox hoodii* increase with overgrazing and *Bromus tectorum* tends to invade. Other species within this habitat type probably will respond to grazing as they do in the *Festuca idahoensi* series.

Range management.--The primary use of this uncommon habitat type most often will be as big-game winter range. Management considerations for the major browse, *Purshia tridentata*, are discussed in the *PUTR/AGSP* h.t. section. Livestock grazing should be permitted only when not in conflict with game use. Requirements of the major herbaceo forage species, *Agropryon spicatum* and *Festuca idahoensis*, are discussed in the *AGPS/BOGR* and *FEID/AGSP* h.t. sections.

Noted elsewhere.--Vegetation similar to our *PUTR/FEID* h.t. occurs at least in regon and Washington. Franklin and Dyrness (1969) identified a *Purshia tridentata--estuca idahoensis* community, and Hall (1973) a *Purshia tridentata--Agropyron--Festuca* ommunity-type for central and eastern Oregon. Daubenmire described a *PUTR/FEID* h.t. or eastern Washington that differs principally in its greater abundance of annuals han in our Montana type.

Cercocarpus ledifolius/Agropyron spicatum h.t.

(*CELE/AGSP* h.t.)

Distribution and environment.--The *CELE/AGSP* h.t.is similar in many ways to abitat types within the *Purshia tridentata* series. These types usually occur as ather small patches of only a few acres, they are generally restricted to rather dry, ocky, southerly exposures, and they have a high potential for being very important inter habitat for big game. The stands we examined occurred on limestone outcrops, ut we suspect the type is not confined to this material. They were found at elevations from 4,500 to 6,800 ft (1,400 to 2,100 m) in southwestern Montana. The soils ere shallow and very rocky, and the slopes usually steep (up to 100 percent).

Vegetative composition.--*Cercocarpus ledifolius* obviously dominates this type fig. 25), but species of *Artemisia*, *Chrysothamnus*, and *Juniperus* may also be present. n some cases, *Cercocarpus ledifolius* can be more than 10 ft (3 m) tall, but more ommonly it ranges in height from 5 to 8 ft (1.5 to 2.5 m). Usually it occurs in rather pen stands with sparse herbaceous understory and considerable bare soil. Such low hrubs as *Artemisia frigida* and *Gutierrezia sarothrae* are common. The herbaceous cover onsists primarily of *Agropyron spicatum*, but *Stipa comata*, *Oryzopsis hymenoides*, and *oeleria cristata* are often present as well (appendix E1.1).

igure 25.--*Cercocarpus ledifolius/Agropyron spicatum* h.t. steep limestone slopes near the Lewis and Clark Caverns in southwestern Montana.

Productivity.--Production data for this habitat type in Montana are not available. In central Idaho, however, Schlatterer (1972) reported a wide range in total productivity--from 500 to 1,500 lb/acre (560 to 1,680 kg/ha). We believe production of most of our western Montana stands probably will not exceed about 800 lb/acre (896 kg/ha). Most of the forage is produced by *Agropyron spicatum*, *Stipa comata*, and *Cercocarpus ledifolius*.

Changes with grazing.--The principal shrub, *Cercocarpus ledifolius*, is highly palatable to big game in the winter. It is only moderately palatable to sheep and cattle. Repeated heavy utilization in the winter may cause a decrease in reproduction and vigor of the smaller *Cercocarpus* plants which are entirely within reach of the animals. Heavy summer grazing ordinarily causes a decrease in *Agropyron spicatum* and *Oryzopsis hymenoides*; the unpalatable shrubs, *Artemisia tridentata*, *Artemisia frigida*, and *Gutierrezia sarothrae*, usually increase. Such forbs as *Erigeron caespitosa* and *Phlox hoodii* may also increase conspicuously. *Stipa comata* and *Koeleria cristata* may increase initially under heavy grazing, but continued overuse will cause these two grasses to decline. Other species within the habitat type probably respond to grazing as they do in the *Agropyron spicatum* series.

Range management.--The primary value of the *CELE/AGSP* h.t. in western Montana is as big-game winter range. *Cercocarpus ledifolius* is a preferred winter browse for both deer and elk. The type is relatively poor livestock range. *Cercocarpus ledifolius* is not very palatable to either cattle or sheep in the summer, and the type usually occurs on rather steep, rocky slopes not readily accessible to livestock. Consequently conflicts in use between livestock and wildlife are unlikely except on those sites low enough in elevation to be used by livestock in the winter.

Cercocarpus ledifolius appears to respond to use similarly to *Purshia tridentata* as described in the *PUTR/AGSP* h.t. section. In Utah, fall clipping of all current growth of *Cercocarpus ledifolius* reduced subsequent twig growth; however, utilization to a level where 1 to 2.5 in (2.5 to 6.4 cm) of current twigs remained actually stimulated production the following year compared to unclipped plants (Ellison 1960). To maintain productivity of this valuable shrub, Garrison (1953) recommends that winter utilization of current growth that is within reach of the animals not exceed 50 to 60 percent. Little available browse is produced once the plant tops have grown beyond normal grazing height. In such cases, top pruning may improve browse availability (Thompson 1970).

Noted elsewhere.--Schlatterer (1972) described a *Cercocarpus ledifolius--Agropyron spicatum* community-type and Lewis (1975) a *CELE/AGSP* h.t. associated with limestone soils in central Idaho and northern Nevada. They appear somewhat more mesic than the Montana type in that they contain *Symphoricarpos oreophilis* but not *Artemisia frigida*, *Gutierrezia sarothrae*, and *Stipa comata*. Scheldt and Tisdale (1970) indicate that a *Cercocarpus ledifolius* type with *Agropyron spicatum* as the principal understory species is scattered across central and southern Idaho. However, they did not find the type confined to limestone soils. A *Cercocarpus ledifolius*-grass community type that occurs on lavas was described by Hall (1973) for eastern Oregon. This type differs considerably from the Montana type in that it may contain *Carex geyerii*, *Calamagrostis rubescens*, and *Festuca idahoensis*.

Rhus trilobata /Agropyron spicatum h.t.

(*RHTR/AGSP* h.t.)

Distribution and environment.--Habitat types within the *Rhus trilobata* series are found primarily along southerly and westerly facing low-elevation breaks into tributaries of the Missouri River. The type commonly occurs as patches or strips (fig. 26) on the convex shoulders and slopes that descend from the sedimentary benchlands or terraces above the rivers and streams. All stands we observed were below 4,500 ft (1,400 m) elevation. The soils are typically shallow, rocky, and usually of sandstone parent material. Ordinarily, considerable amounts of rock and bare soil are exposed on the soil surface (appendix D). This is considered a fairly arid vegetation series. The *RHTR/AGSP* h.t. is the predominant type within the series.

Figure 26.--*Rhus trilobata/Agropyron spicatum* h.t. on a moderately steep south slope along the Yellowstone River near Big Timber in south central Montana.

Vegetative composition.--The shrubby *Rhus trilobata* overstory is accompanied by a predominantly *Agropyron spicatum* understory. The amount of *Rhus trilobata* varies considerably from only 1 or 2 percent canopy cover to well over 25 percent. A variety of other shrubs such as *Chrysothamnus* spp., *Artemisia tridentata*, *Ribes cereum*, and even *Prunus virginiana* and *Amelanchier alnifolia* may be associated with *Rhus trilobata* (appendix E12), but they are seldom abundant. *Opuntia polyacantha* and *Artemisia frigida* are the most common low shrubs. *Agropyron spicatum*, the most abundant grass, may be accompanied in some cases by substantial amounts of either *Oryzopsis hymenoides* or *Agropyron smithii*. *Bromus tectorum* is commonly an abundant annual. The more conspicuous forbs are *Vicia americana*, *Chrysopsis villosa*, *Achillea millefolium*, and *Sphaeralcea coccinea*.

Productivity.--We did not sample this habitat type for herbage production. Very likely, however, it will produce about as much as either the *AGSP/BOGR* h.t. or the *AGSP/AGSM* h.t., between 500 and 700 lb/acre (560 and 784 kg/ha). Judging from our canopy-cover data (appendix E12), approximately half of this production will consist of forage grasses, about a third will be shrubs, and the remainder will be forbs. The forbs and shrubs are of little forage value.

Changes with grazing.--Heavy summer use of the type by livestock usually causes a decrease in the amount of *Agropyron spicatum* and *Orhyzopsis hymenoides*, and an increase in *Chrysothamnus nauseosus*, *Opuntia polyacantha*, *Chrysopsis villosa*, and possibly *Rhus trilobata*. These low-lying river bank areas are often deer winter range. Repeated heavy winter use by big game will cause a decline in *Prunus virginiana* and possibly *Rhus trilobata*. *Bromus tectorum* is the principal species that invades with overgrazing

Range management.--This type is generally more valuable for wildlife habitat than for livestock range. It occurs primarily as stringers along river breaks and receives considerable use by deer in the winter, especially if other browse is limited. Its major shrub, *Rhus trilobata*, however, is low in palatability for livestock. The greatest value of the type for livestock would be for early spring or late fall grazing. *Agropyron spicatum* is the key forage species for livestock. Management considerations for this grass are discussed in the *AGSP/BOGR* h.t. section.

Rhus trilobata /*Festuca idahoensis* h.t.

(*RHTR/FEID* h.t.)

Distribution and environment.--This infrequent type occurs primarily as patches or strips on the convex shoulders and slopes that drop off from the sedimentary benchlands or terraces above tributaries of the Yellowstone and Missouri Rivers (fig. 27). The stands we observed were below 4,500 ft (1,400 m) elevation. Soils are typically shallow, rocky, and usually of sandstone parent material. Considerable rock and bare soil are commonly exposed on the soil surface (appendix D). The *RHTR/FEID* h.t. is slightly less arid than the *RHTR/AGSP* h.t.

Figure 27.--*Rhus trilobata/Festuca idahoensis* h.t. along the shoulder of benches droppi into the Missouri River southwest of Great Falls, Montana.

Vegetative composition.--The presence of *Festuca idahoensis*, even though *Aropyron spicatum* may be more abundant, characterizes this habitat type. *Bouteloua gracilis*, *Stipa comata*, and *Carex pennsylvanica* were other conspicuous graminoids in the example of this type sampled (appendix E12). *Chrysopsis villosa*, *Achillea millefolium*, *Cerastium arvense*, and *Phlox hoodii* were the most abundant forbs.

Productivity.--Total production in the *RHTR/FEID* h.t. probably is slightly greater than in the *RHTR/AGSP* h.t., or about 600 to 800 lb/acre (672 to 896 kg/ha). Canopy-cover data (appendix E12) suggest that about half of the production consists of palatable graminoids, about a fourth shrubs, and the remainder forbs. Neither the shrubs nor forbs contribute much to forage production since they consist primarily of species low in palatability.

Changes with grazing.--The principal forage grasses that probably decline with continued heavy summer use of this type are *Agropyron spicatum*, *Festuca idahoensis*, and *Stipa comata*. Species that usually increase are *Chrysopsis villosa*, *Artemisia frigida*, *Achillea millefolium*, and *Cerastium arvense*. Continued overgrazing by livestock may cause *Rhus trilobata* to increase; however, repeated heavy winter use by big game may cause this shrub to decline. *Bromus tectorum* frequently invades with overgrazing or where rodent disturbance exists.

Range management.--As with the *RHTR/AGSP* h.t., this uncommon and rather isolated type probably has greatest value as wildlife habitat. Although not highly palatable, *Rhus trilobata* may receive considerable use by deer in the winter where winter range is limited. Probably the greatest value to livestock would be as small areas of spring-fall range. Management implications for the principal livestock forage species, *Agropyron spicatum* and *Festuca idaheonsis*, are discussed in the *AGSP/BOGR* and *FEID/AGSP* h.t. sections.

Sarcobatus vermiculatus /Agropyron smithii h.t.

(*SAVE/AGSM* h.t.)

Distribution and environment.--The *Sarcobatus vermiculatus* series is most commonly encountered as narrow bands along the flood plains of rivers and streams in low precipitation areas throughout the western part of the State. We also have seen it in rather broad expanses along flat lakeshores and playas in north central Montana. *Sarcobatus vermiculatus* typically grows on heavy, poorly drained saline or alkaline soils.

Vegetative composition.--Although *Sarcobatus vermiculatus* is the dominant shrub in this type (fig. 28), *Atriplex nuttallii* and *Chrysothamnus viscidiflorus* may also be present. Canopy cover of *Sarcobatus vermiculatus* may be low (less than 10 percent), yet the stature of the plant compared to associated vegetation creates a shrubby aspect. *Agropyron smithii* is the dominant understory species. *Bouteloua gracilis*, *Stipa comata*, *Artemisia frigida*, and *Opuntia polyacantha* may also be present, but forbs are characteristically scarce. This series contains fewer plant species (floristically poorer) than any of the other grassland or shrubland series described.

Productivity.--We did not sample this type for production. However, judging from our canopy-cover data (appendix E13), perhaps as much as two-thirds of the vegetation consists of such palatable grasses as *Agropyron smithii* and *Poa juncifolia*. With the exception of *Atriplex nuttalii*, shrubs and forbs do not contribute appreciably to forage production.

Figure 28.--*Sarcobatus vermiculatus/Agropyron smithii* h.t. on alkaline flats west of Great Falls.

Changes with grazing.--*Agropyron smithii, Poa juncifolia, Stipa comata,* and *Atriplex nuttallii* can be expected to decrease with continued overgrazing of this type. Very likely *Sarcobatus vermiculatus, Opuntia polyacantha,* and *Artemisia frigida* will be the principal species that increase. *Bouteloua gracilis* may also increase since its low growth form enables it to withstand grazing.

Range management.--Although not very palatable, *Sarcobatus vermiculatus* may be browsed somewhat by cattle, deer, and antelope in the winter. This shrub is poisonous to sheep and the type is not desirable sheep range. The valley-bottom location makes the type best suited for late fall, winter, and early spring cattle range. Management of the principal forage species, *Agropyron smithii*, is discussed in the *AGSP/AGSM* h.t. section. This rhizomatous grass is able to withstand heavy fall and winter use; greater care must be taken with spring use.

Sarcobatus vermiculatus /Elymus cinereus h.t.

(*SAVE/ELCI* h.t.)

Distribution and environment.--The *SAVE/ELCI* h.t. (fig. 29) occurs primarily as a rather narrow band along the flood plains of rivers and streams in low precipitation areas throughout the western part of the State. *Sarcobatus vermiculatus* typically grows on heavy, poorly drained saline or alkaline soils. The environmental differences between this and the *SAVE/AGRM* h.t. are uncertain. The *SAVE/ELCI* h.t. appears to occur more on the concave toe slopes where the soils may be better drained and less saline than they are on the flat.

Vegetative composition.--The presence of clumps of *Elymus cinereus* differentiates the *SAVE/ELCI* h.t. from the *SAVE/AGSM* h.t. *Agropyron smithii* is usually abundant beneath the *Sarcobatus vermiculatus* overstory; such graminoids as *Agropyron spicatum, Koeleria cristata,* and *Carex filifolia* may also be present. Forbs, such as *Aster chilensis, Iva axillaris,* and *Sphaeralcea coccinea*, occur more commonly here than in the *SAVE/AGSM* h.t.

Figure 29.--*Sarcobatus vermiculatus/Elymus cinereus* h.t. on toe clopes into the Ruby River south of Alder in southwestern Montana.

Productivity.--We did not measure total production in this type. Our canopy-cover data (appendix E13) suggest that at least half of the production consists of such palatable grasses as *Agropyron smithii* and *Agropyron spicatum*. Neither the shrubs nor forbs are valued forage.

Changes with grazing.--Overgrazing of this type commonly causes *Agropyron spicatum* and *Agropyron smithii* to decline. If heavy use persists, *Koeleria cristata*, *Elymus cinereus*, and possibly *Chrysothamnus viscidiflorus* will probably decrease as well. The principal species that increase are *Sarcobatus vermiculatus*, *Gutierrezia sarothrae*, and *Opuntia polyacantha*.

Range management.--*Sarcobatus vermiculatus* is used somewhat by cattle, deer, and antelope in the winter but is poisonous to sheep. Best use of this low-elevation type probably is as late fall, winter, and early spring cattle range. *Agropyron smithii* and *Agropyron spicatum* are principal forage producers. Management considerations for these two grasses are discussed in the *AGSP/BOGR* and *AGSP/AGSM* h.t. sections. *Elymus cinereus* may also be an important forage producer. Krall and others (1971) found that early spring grazing is very harmful to this grass. They suggest that no more than 50 percent of the herbage of *Elymus cinereus* be grazed prior to its boot stage of development, and that spring grazing not take place every year.

OTHER VEGETATION TYPES

What appear to be climax shrubland and grassland communities that do not fit our classification were occasionally encountered in western Montana. We suspect that some of these represent scarce but valid habitat types.

Foremost among these suspect habitat types is a shrub community in southwestern Montana dominated by *Artemisia cana*. This type occurs on deep, loamy, alluvial soils along some mountain streams at elevations usually over 6,000 ft (1,827 m). It has been observed as rather small patches less than 5 acres (2 ha) in size in and near Yellowstone National Park. *Artemisia tridentata* ssp. *vaseyana* may be intermixed with the dominant *Artemisia cana*. The grass-forb understory is similar to that found in the more moist portions of the *ARTR/FEID* h.t. The type probably should be designated as an *Artemisia cana/Festuca idahoensis* h.t. (*ARCA/FEID* h.t.). Schlatterer (1972) described a somewhat similar *ARCA/FEID* community that occurs on depositional soils in the Sawtooth Mountains of central Idaho.

At least two other sagebrush habitat types probably occur in southwestern Montana on dry, alkaline, alluvial soils. One is dominated by *Artemisia longiloba* and the other by *Artemisia pedatifida* (Morris and others 1976). Both of these relatively uncommon species are dwarfed shrubs; the latter is a subshrub 4 to 6 in (10 to 15 cm) high. The primary herbaceous associates appear to be *Agropyron spicatum* and *Festuca idahoensis*. Both *Artemisia longiloba/Agropyron spicatum* and *Artemisia longiloba/Festuca idahoensis* (*ARLO/FEID*) communities are reported to occur in central Idaho (Schlatterer 1972; Tisdale and others 1965), and an *ARLO/FEID* h.t. in northern Nevada (Zamora and Tueller 1973). Very likely we have an *ARLO/FEID* h.t. in southwestern Montana as well. We also observed a single example of what appears to be an *Artemisia pedatifida/Festuca idahoensis* h.t. in Beaverhead County near Bannock Pass.

Although we have listed only the *SAVE/AGSM* and *SAVE/ELCI* habitat types in the *Sarcobatus vermiculatus* series, very likely a third type exists in which *Distichlis stricta* is the principal understory. Daubenmire (1970) reported a *Sarcobatus vermiculatus/Distichlis stricta* (*SAVE/DIST*) h.t. for eastern Washington. Based on our own observations and reports from others, we believe a *SAVE/DIST* h.t. may also occur in western Montana.

Communities dominated by *Elymus cinereus* occur occasionally in western Montana, generally as small patches on saline-alkaline soils along low-elevation streambanks. However, in Lake County approximately 6 miles (10 km) west of Polson, this grass dominates extensive areas of a broad valley. In this stand, *Agropyron smithii* and *Puccinellia distans* were the most common associates; a few widely scattered *Chrysothamnus nauseosus* shrubs also occurred. Quite possibly an *Elymus cinereus/Agropyron smithii* h.t. would be a valid type for western Montana.

Composition of the grassland and shrubland vegetation of the Pryor Mountains in south central Montana is somewhat different from that in the rest of western Montana. This may be attributable to the occurrence of species affiliated with flora of the Central Rocky Mountains. Our sampling of the Pryor Mountain vegetation was not adequate to define many of these differences. An example was encountered on East Pryor Mountain at an elevation of approximately 8,500 ft (2,600 m) where extensive areas were dominated by *Carex scirpoides* (40 percent canopy cover) and *Festuca idahoensis* (10 percent canopy cover). Twenty-seven different forbs were encountered, the most abundant of which were *Phlox hoodii* and *Geum triflorum*. Extensive sheep grazing in the past may have significantly altered composition of vegetation on this area to preclude identifying it with previously described habitat types. On the other hand, if the vegetation has not been appreciably altered, this type may represent a valid *Festuca idahoensis/Carex scirpoides* h.t.

We did not attempt to classify the vegetation occurring along the relatively narrow riparian zones. Such stringers of willows and sedges along the edges of streams and marshes do not occupy much area but are critical for stream channel stabilization and fisheries. Riparian vegetation merits intensive, separate study.

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APPENDIX A

APPENDIX A —

METHODS

Our approach to the development of a habitat type classification for grasslands and shrublands was conditioned by several somewhat controversial concepts: (1) no two plant communities are identical; (2) natural vegetation does not occur in discrete units, but rather as a continuum along complex environmental gradients; (3) land and dependent resources are readily managed as discrete areal units, but not as points on a continuum; and (4) similar plant communities should respond to management in similar ways. The problem, then, becomes one of alining plant communities along a continuum of vegetation similarities and expected response to perturbations, and then partitioning this continuum into relatively homogeneous units that have similar biotic potentials and anticipated responses to management. The objective, of course, is to arrive at a logical and ecologically sound classification that partitions the spectrum of natural environmental conditions and reflects existing vegetation patterns.

Ideally, communities of *climax* vegetation should be used for developing a classification based on biotic potentials. However, the presence of livestock in western Montana for more than 100 years has left few areas unchanged by grazing. The scarcity of ungrazed areas necessitated sampling both near-pristine areas as well as areas subject to some grazing disturbance that, according to our judgment, had not altered the vegetation appreciably. On these areas, a change in the relative amount of a species was acceptable, but not a pronounced alteration in species present. Severely altered communities usually were easily identified, but determining the degree of change at lesser levels of disturbance was very subjective unless undisturbed areas on similar sites nearby were available for comparison.

Field crews were instructed to sample the following: all relic areas and exclosures, areas typical of large expanses of grasslands and shrublands not severely altered by grazing, areas typical of small recurring grasslands and shrublands, and distinct fence-line contrasts caused by differential grazing. The latter were sampled to provide data on composition changes attributable to grazing. Areas to be avoided, in addition to those severely overgrazed, included all areas that had obviously been treated for brush control, those artificially seeded or irrigated, those crossing sharp ecotones, and those not typical of either large expanses or smaller recurring sites.

A relatively uniform 20x20 m macroplot was selected and permanently marked in each community (stand) that was intensively sampled. The macroplot was selected to represent the stand under consideration. Forty 2x5 dm microplots were established on each macroplot; these microplots were evenly distributed along two randomly selected transects crossing the macroplot. A list of species occurring on the macroplot was prepared, and canopy cover was estimated by species and vegetation classes on each microplot. Many ephemeral species were missed, however, because many areas were sampled after these species had dried and disintegrated. The amounts of litter, bare soil, and rock on the microplots were also estimated. The general topographic and edaphic characteristics of each stand were recorded. A total of 355 stands throughout western Montana were sampled in this manner; 289 of these were in grasslands, and 6 were in shrublands.

General reconnaissance data were obtained from an additional 225 stands to supplement the geographical coverage provided by the intensively sampled stands. These data consisted of general estimates of canopy cover by species on selected sites. We made a special effort to obtain information useful for evaluating successional trends and to supply at least limited data on suspected habitat types not sampled otherwise.

Plant species of uncertain identity were collected and returned to the laboratory for verification. A total of 494 different species representing more than 200 genera were recorded. Nomenclature follows Hitchcock and others (1955-69), Booth and Wright (1966), and Booth (1972), with Hitchcock and others given preference. A collection of voucher specimens is maintained at the Intermountain Station's Forestry Sciences Laboratory in Bozeman.

Vegetation data were processed to obtain the following species parameters: absolute and relative frequency, absolute and relative canopy cover, and a species importance value consisting of relative frequency plus relative cover. The degree of similarity between individual stands was determined numerically by Sorensen's coefficient, K=100 (2c/a+b) (Gauch and Whittaker 1972; Beals 1973).

Ordination (Bray and Curtis 1957) of approximately 200 stands using, successively, species presence, importance values, relative canopy cover, and canopy cover scaled to different values assisted formulation of ideas on logical alinment of stands. Subsequent cluster analyses (Sokal and Sneath 1963) were of limited value for alining stands into logical groups. We believe that the relatively few species exerting a potentially dominant role as expressed by a combination of morphology and amount of canopy cover should be stressed in the development of a meaningful classification. The importance of the potentially dominant role of these species appeared to be overshadowed in our ordination and cluster analyses by the great variation in presence and cover of minor species. The large variability of the many forb species especially appeared to overshadow basic similarities and dissimilarities inherent in the graminoid and shrub components which could be detected otherwise. Since we were dealing primarily with somewhat less than pristine conditions, species presence and composition within each stand had to be viewed flexibly and weight had to be given to those species considered significant indicators of environmental differences. The forbs generally appeared more accidental on these areas than the graminoids and shrubs; in any event, most forbs appeared to be unreliable indicators of suspected environmental differences. Rather than intensively pursue the refinement of groupings obtained by using these numerical techniques, we decided to rely heavily upon the use of synthesis or association tables (Mueller-Dombois and Ellenburg 1974).

The stands were first grouped into "series" determined by the primary climax dominant species. This determination was based upon judgment conditioned by the results of computer analysis and experience. Shrubs were generally considered first order dominants, and graminoids second order dominants. No single forb species appeared to assume an overall dominant position in any of the communities sampled. If the dominant species of the stand had a minimum canopy cover of approximately 5 percent combined with a frequency of 25 to 50 percent depending upon the species growth habit, the stand would qualify for that species series. These minimum cover and frequency values were merely guides which were adjusted somewhat depending upon estimated grazing alteration.

Stands assigned to a series were placed in a "dynamic" association table which permitted horizontal alinment of stands and vertical alinment of species. The position of stands and species were adjusted until they were arranged into what appeared to be a sensible order along a continuum of vegetation similarity. Factors considered in selecting species upon which to base stand alinments included species dominance in the stands, suspected affinity to specific environmental conditions, and constancy of species within proposed groups. Partitioning of the continuum into "habitat types" followed. Usually one end of the series continuum differed obviously from the other, and usually this difference appeared to reflect a moisture gradient. Different species tended to occur at opposite ends of the continuum, but other species were so widely scattered that they appeared accidental; very likely this difference in species behavior reflects differences in overall ecological amplitude of the various species within the series.

Actual separation of habitat types was based upon dominant and codominant species, reasonable consistency of the secondary species, and the likelihood of similar anticipated response to management. A "phase" was designated only when consistent dissimilarities of one or more secondary species suggested a real environmental difference, but one not sufficiently great to warrant separate habitat type status.

A dichotomous vegetation key was prepared to assist recognition of habitat types and phases in the field. The key was tested for reliability both by checking against the data for each of the 580 stands sampled and by field use.

To develop management-related information on important habitat types, we conducted additional field studies and, by thoroughly reviewing relevant literature, related previous research findings to our defined habitat types. The need for specific information on successional relations, forage productivity, and the relationship of soils to the defined habitat types prompted the additional field studies.

Information on successional relations attributable to grazing was developed by intensive field sampling of 20 pairs of differentially grazed stands representing 8 different habitat types. These pairs consisted of inside-outside exclosure comparisons as well as other fence-line contrasts under obviously different grazing intensities. A "t" test was used to determine whether differences between the canopy cover of a species were statistically valid or simply a result of sample variation. (Comparisons of paired-stands are shown in appendix G). Data from the intensively sampled paired-stands were supplemented by observations of more than 140 areas where we specifically sought information on compositional changes attributable to grazing. This information consisted of qualitative judgments based on adjacent areas that had been differentially grazed. In addition, numerous publications relating to grassland and shrubland vegetation in the Northern Rocky Mountains were scanned for information on compositional changes caused by grazing. Where possible, we related these published findings to our classification categories. The consistency of reaction of species to grazing was then summarized by habitat types.

The potential of different sites for producing vegetation differs greatly in the highly varied environment of the Northern Rocky Mountains. Since habitat types reflect overall site potential, we can expect total vegetation biomass and consequent forage production to differ greatly between habitat types. In a separate study we measured above-ground biomass production on 12 of the more important habitat types as judged from amount of area occupied and potential value for producing forage. Each of the 12 habitat types was represented by 2 to 4 stands selected to represent the range in production that might be expected within a given habitat type. Production on each stand was sampled over 3 consecutive years, 1974 through 1976, to evaluate the variability in production that occurs between years and is attributable to weather. During this 3-year period annual precipitation in western Montana ranged from approximately three-fourths to 1-1/2 times the long-term average; April through July precipitation ranged from approximately one-half to 1-1/2 times the long-term average. Production was determined by a double sampling technique (clipping and estimation) on 50 permanent 4.8 ft^2 (0.46 m^2) plots distributed in random 5-plot clusters on each stand. The sampling intensity was designed to produce data that, for between-stand comparisons, have a 95 percent probability of estimating vegetation classes and major species within at least 20 percent of the population mean (Mueggler 1976). The summarized data are included in the discussion of the appropriate habitat type descriptions in this report. A comprehensive evaluation of forage production variability within and between habitat types, and between years, will be published later.

The physical and chemical properties of soils on important habitat types were deter-mined through a cooperative study with the Soils Department of Montana State University. Soil profiles were described and soil properties analyzed on 22 stands selected to represent 8 different habitat types. All 22 of these stands were part of the aforementione study to determine biomass productivity. Correlations between soil characteristics and herbage production were determined (Munn 1977). The soils information for the stands where data were collected is shown in appendix C.

Other information on management implications, e.g., species palatability, proper use, season of use, range improvements, etc., was obtained primarily from published literature and existing guides for range managers. Relevant information of this sort is summarized in the discussion for each habitat type. The source of the information is cited where appropriate.

APPENDIX B

APPENDIX B —

WESTERN MONTANA ENVIRONMENT

Topography and Geology

Montana is divided from west to east into three approximately equal sections of vastly different topography. The western third is part of the northern extension of the Rocky Mountains, the eastern third is the western edge of the Great Plains, and the central section is a mixture of plains and isolated mountain masses. The mountainous western portion covered by our vegetation classification consists of some 40 individual mountain ranges up to 20 miles (32 km) wide and from 50 to 100 miles (80 to 160 km) long (Perry 1962). Most of the mountain ranges lie parallel and are oriented in a northwesterly-southeasterly direction. Mountain elevations average only 6,000 ft (1,800 m) in northwestern Montana; these elevations gradually increase to 10,000 ft (3,000 m) as one proceeds southward to the Beartooth Plateau near Yellowstone National Park.

The mountain ranges alternate with broad, nearly level valleys 5 to 20 miles (8 to 32 km) wide and 25 to 75 miles (40 to 120 km) long. The average elevation of the major valleys also increases from 2,900 ft (880 m) around Kalispell in northwestern Montana to 5,400 ft (1,650 m) in the southwestern part of the State near Dillon. The floors of most of the major valleys consist of sediments deposited in lakes formed in the valleys during the late Tertiary and early Quaternary Periods.

The geologic history of Montana covers well over 500 million years and has been thoroughly described by Perry (1962). The varied forces at work since the Precambrian Era are responsible for the highly varied topography and rock strata that strongly influence current vegetation patterns. Therefore, a brief review of the geologic history of western Montana is appropriate.

The basal rock strata of western Montana consists of a complex of Precambrian metamorphics with igneous intrusions and lava extrusions. During the Precambrian Era, inland seas repeatedly formed, sediments were deposited, and Precambrian mountains arose and were subsequently eroded to a plain. The Belt series sediments, which were later consolidated into argillites and quartzites, originated in the Precambrian Era. Inland seas covered western Montana during the Paleozoic Era also depositing primarily limestone sediments. Some of these limestone strata in southwestern Montana are several thousand feet thick.

Invasion and recession of inland seas continued through the Mesozoic Era, with additional depositions consisting primarily of shales and sandstones. The last of the great marine invasions of western Montana occurred during the late Cretaceous Period. At this time also, lava beds up to 5,000 ft (1,500 m) were formed by volcanic activity in portions of western Montana.

The Rocky Mountains first began rising by folding and faulting of the thick layers of sedimentary deposits in the late Cretaceous and early Tertiary Periods. At this time, the Boulder batholith, extending from Helena to beyond Butte, was formed. Most such batholithic intrusions as well as volcanic extrusions occurred in the southwestern part of the State. The folded and faulted mountain masses were nearly leveled by erosion during the latter part of the early Tertiary Period. The second or present stage in mountain development, which is superimposed on the earlier eroded mountain structure,

occurred primarily by block faulting in the middle and late Tertiary Period. Most of these mountains were formed as parallel ranges trending northwest and southeast. Other mountain masses, particularly at the eastern edge of the Northern Rocky Mountains, were created by such forces as vertical uplift (e.g., Beartooth Plateau) and intrusions of igneous material (e.g. Crazy Mountains).

During the late Tertiary Period, large lakes were formed in the numerous valleys between the recently formed mountains. These lakes accumulated sediments up to 2,000 ft (600 m) thick, which are responsible for the present broad, relatively flat valley bottoms consisting of deep, relatively recent sedimentary deposits.

Continental and mountain glaciation altered western Montana during the Pleistocene Epoch. The Cordilleran ice sheet extended some 60 to 70 miles (100 to 115 km) into northwestern Montana, blocked the Clark Fork River, and created Glacial Lake Missoula. This massive lake covered 2,900 mi^2 (7,500 km^2), was up to 2,000 ft (600 m) deep, and left Pleistocene sedimentary deposits on many of the extensive valley floors in the northwestern part of the State. All of the higher mountains were altered by mountain glaciers during this period. Both the Cordilleran and mountain glaciers left deposits of morainal rubble and glacial till.

Soils

Soils in the mountainous regions of western Montana are described by Southard (1973). Forested soils in the drier 12- to 25-in (30- to 64-cm) precipitation zone generally belong to the Gray Wooded great soil group (Cryochrepts, Cryorthods, and Cryoboralfs under the 1968 National Soils Classification System). Brown Podzolic soils (Paleboralfs and Cryorthods) usually are found in the forested areas within the 25- to 50-in (64- to 127-cm) precipitation zone.

On the nonforested sloping and undulating uplands in western Montana, Chestnut, Chernozem, and Calcisol soils (Haploborolls, Argiborolls, and Cryoborolls) predominate. Chestnut, Chernozem, Brown, Calcisol, and Lithosol soils (Haploborolls, Argiborolls, Cryoborolls, and Calciborolls) are found on the nonforested foothills, fans, and terraces. Alluvial soils (Hapludolls and Cryoborolls) are prominent on the bottom lands.

Climate

The climate of western Montana differs greatly over short distances because of the extreme topographic variation. The Continental Divide, which runs in a generally north-south direction, exerts a pronounced influence on the climate. The climate west of the Divide is modified by air mass penetration from the north Pacific Ocean; whereas east of the Divide continental influences predominate. Consequently, areas west of the Divide generally experience cooler summers, milder winters, greater cloudiness, precipitation more evenly distributed throughout the year, and lighter winds than areas east of the Divide (U.S. Dep. Commer. 1971).

Weather records from Kalispell, Missoula, Hamilton, and Butte indicate that approximately 55 percent of the annual precipitation west of the Divide occurs from April through September. For stations adjacent to the mountains east of the Divide, Browning, Choteau, Helena, Bozeman, and White Sulphur Springs, approximately 70 percent of the annual precipitation falls during these months. Late spring (May and June) is the period of greatest precipitation. Areas west of the Divide receive approximately a fourth and areas east of the Divide approximately a third of their total annual precipitation during this period. Heavy snow storms can occur in the mountainous areas as early as mid-September and as late as May. Mountain snow packs are highly variable but may exceed 8 ft (2.5 m).

Mean maximum July temperatures in western Montana range from considerably less than 72°F (22°C) at the higher elevations in the mountains to more than 90°F (32°C) in the lower valleys. Mean minimum temperatures in January range from -2° to 20°F (-19° to 7°C). Maximum temperatures greater than 100°F (38°C) sometimes occur at the lower elevations, while minimum temperatures east of the Divide can fall to -50°F (-45°C) or lower (U.S. Dep. Commer. 1971).

Effective precipitation and temperature are the primary climatic factors governing vegetation distribution. Both of these factors are strongly influenced by topography. Isohyetal lines for Montana are illustrated by Ross and Hunter (1976). Although annual precipitation at the higher elevations on the windward (generally western) side of the mountains often may exceed 40 in (100 cm), rain-shadow areas in adjacent valleys may receive less than 10 in (25 cm). Summer temperatures decrease with elevational increases, which in turn reduce moisture loss from evapotranspiration and improve moisture relations for plant growth. On the Gravelly Range of mountains in southwestern Montana, this decrease in maximum summer temperatures amounted to between 4.7° and 6.3°F (2.6° and 3.5°C) for each 1,000 ft (305 m) elevational rise (Mueggler 1971).

As a direct consequence of the interrelationships between topography and effective precipitation, grasslands and shrublands are generally found on the valley bottoms, low foothills, and many southerly aspects at the higher elevations. Forests occur where moisture stress is less severe. Climatic, topographic, and edaphic balances are so tenuous on some mountain ranges (e.g., Gravelly Range) that the vegetation consists of a mosaic of forests and grasslands with ill-defined causal relationships. From his research into forest-grassland patterns in the Madison Range, Patten (1963) concluded that although the entire holocoenotic environment determines vegetation patterns, the most common limiting factors for tree growth are those affecting water availability.

APPENDIX C —

ENVIRONMENT PARAMETERS FOR IMPORTANT HABITAT TYPES

General environmental parameters, soil physical properties, and soil chemical properties are given in separate tables for eight important habitat types: *STCO/BOGR*, *AGSP/BOGR*, *AGSP/AGSM*, *FESC/AGSP*, *FESC/FEID*, *FEID/AGSP*, *FEID/AGCA*, and *ARTR/FEID*.

C1. — General

General environmental parameters on stands selected to span the range in vegetative production within eight important habitat types

Stand No.	Average production[1]	Elevation	Aspect	Slope	Estimated precipitation[2]	Estimated potential evapotrans-piration[3]	Estimated frost-free season[4]
	kg/ha	*m*		[illegible]	[illegible]	[illegible]	*Days*
Stipa comata/Bouteloua gracilis h.t.							
102	271	1,395	SW	5	25	57	112
180	787	1,536	W	10	38	56	96
358	949	1,152	NE	12	33	64	115
Agropyron spicatum/Bouteloua gracilis h.t.							
9	483	1,414	W	25	33	60	115
149	488	1,524	SW	2	73	56	90
179	867	1,359	E	1	36	65	121
Agropyron spicatum/A. smithii h.t.							
83	762	1,344	S	11	28	48	92
248	900	1,377	SE	36	30	64	110
Festuca scabrella/Agropyron spicatum h.t.							
232	998	1,014	N	7	71	53	117
87	1,346	1,591	S	4	28	41	88
Festuca scabrella/Festuca idahoensis h.t.							
304	1,261	1,143	NE	18	48	53	115
372	1,597	2,157	S	19	79	42	81
208	1,828	2,011	SE	16	53	39	60
Festuca idahoensis/Agropyron spicatum h.t.							
27	734	2,228	S	7	48	37	82
105	834	1,786	SW	12	46	44	98
23	1,375	1,743	NW	12	38	59	110
28	1,449	2,234	N	12	48	37	82
Festuca idahoensis/Agropyron caninum h.t.							
125	1,338	2,438	SW	9	43	36	32
41	1,727	2,170	E	7	46	39	53
56	1,874	2,353	SE	13	61	37	69
Artemisia tridentata/Festuca idahoensis h.t.							
272	854	1,926	W	10	48	37	70
140	1,208	2,090	NE	19	43	38	65
46	1,618	2,145	NE	9	46	39	53

[1] Air-dry vegetation production averaged over a 3-year period.
[2] USDA Soil Conservation Service 1968.
[3] Caprio 1973.
[4] Caprio 1965.

C2. — Soil Physical Properties

Soil physical properties for stands selected to span range in vegetative production within eight important habitat types

Stand No.	Average production	Horizon	Thickness	Texture Sand	Texture Silt	Texture Clay	Coarse fragments	Bulk density	Available water	Parent material
	kg/ha		*cm*	- - - -	- - Percent	- - - -	- -	*gm/cc*	*cm*	
Stipa comata/Bouteloua gracilis h.t.										
102	271	A	16	31	52	17	14	1.52		
		B	36	57	27	16	15	1.28		metamorphic
		Solum	52	49	35	16	15	1.35	4.4	alluvium
		C	172	63	26	11	24	1.31		
180	787	A	8	44	12	44	1	1.11		
		B	45	37	35	28	2	1.50		calcareous
		Solum	53	38	32	30	2	1.44	9.1	sandstone
		C	18	44	36	20	--	--		
[illegible]	949	A	13	58	22	20	1	1.07		
		B	28	42	36	22	1	1.24		
		Solum	41	47	32	21	1	1.19	4.5	sandstone
		C	162	43	42	15	3	1.38		
Agropyron spicatum/Bouteloua gracilis h.t.										
[illegible]	483	A	18	44	36	20	22	0.97		
		B	0	--	--	--	--	--		
		Solum	18	44	36	20	22	0.97	1.3	metamorphic
		C	48	61	21	18	12	1.53		
149	155	A	15	57	25	18	30	1.02		
		B	26	63	13	24	60	1.70		mixed
		Solum	41	61	17	22	49	1.45	2.7	alluvium
		C	99	69	11	20	47	1.21		
179	867	A	10	42	28	30	26	1.11		
		B	38	50	20	30	7	1.37		igneous
		Solum	48	48	22	30	11	1.32	7.0	alluvium
		C	86	64	21	15	38	2.06		
Agropyron spicatum/A. smithii h.t.										
83	762	A	25	54	19	27	8	1.00		
		B	0	--	--	--	--	--		
		Solum	25	54	19	27	8	1.00	2.7	igneous
		C	157	46	40	14	3	1.47		
248	900	A	20	30	39	31	27	1.08		
		B	10	36	33	31	31	0.99		sandstone
		Solum	30	32	37	31	28	1.05	3.0	siltstone
		C	48	46	31	23	58	1.53		
Festuca scabrella/Agropyron spicatum h.t.										
232	998	A	15	42	32	26	4	1.16		
		B	28	43	14	43	4	1.41		
		Solum	43	43	20	37	4	1.32	7.8	igneous
		C	132	20	23	57	14	1.37		
87	1,346	A	25	49	26	25	23	1.21		
		B	0	--	--	--	--	--		mixed
		Solum	25	49	26	25	23	1.21	2.8	outwash
		C	102	55	23	22	21	1.71		

(con.)

Stand No.	Average production	Horizon	Thickness	Texture Sand	Silt	Clay	Coarse fragments	Bulk density	Available water	Parent material
	kg/ha		cm	- - - - - - Percent	- - - - - -			[illegible]	[illegible]	
Festuca scabrella/Festuca idahoensis h.t.										
304	1,261	A	23	28	52	20	5	0.85		
		B	18	44	42	14	[illegible]	1.12		
		Solum	41	35	48	17	13	0.97	3.0	metamorphic
		C	69	31	48	21	21	1.70		
372	1,597	A	28	31	52	17	15	0.75		
		B	46	27	55	18	34	1.21		
		Solum	74	28	54	18	27	1.04	4.0	metamorphic
		C	41	24	54	22	45	1.28		
208	1,828	A	30	57	27	16	19	1.21		
		B	60	53	26	21	34	1.87		
		Solum	90	54	26	20	29	1.65	9.9	metamorphic
		C	13	50	24	26	12	--		
Festuca idahoensis/Agropyron spicatum h.t.										
27	734	A	21	24	51	25	30	0.85		
		B	23	26	47	27	26	1.00		
		Solum	44	25	49	26	28	0.93	3.5	limestone
		C	41	24	34	42	29	0.97		
105	834	A	28	57	27	16	29	1.32		
		B	61	55	28	17	24	1.64		
		Solum	89	56	28	16	26	1.54	7.8	igneous
		C	61	76	15	9	20	1.58		
23	1,375	A	20	65	21	14	17	1.18		
		B	38	69	19	12	13	1.46		
		Solum	58	68	20	12	14	1.36	4.6	metamorphic
		C	81	65	20	15	12	1.65		
28	1,449	A	28	25	50	25	9	0.61		
		B	23	27	37	36	16	1.15		
		Solum	51	26	44	30	12	0.85	5.4	limestone
		C	58	29	27	44	21	1.19		
Festuca idahoensis/Agropyron caninum h.t.										
125	1,338	A	23	58	32	10	10	0.72		
		B	15	54	32	14	33	1.51		
		Solum	38	56	32	12	19	1.03	2.8	igneous
		C	56	63	24	13	56	2.50		
41	1,727	A	51	35	44	21	2	0.85		
		B	48	36	42	22	28	1.31		
		Solum	99	35	43	22	15	1.07	7.4	igneous
		C	41	32	45	23	32	0.85		
56	1,874	A	56	47	11	42	1	0.89		
		B	68	41	33	26	5	1.35		
		Solum	124	44	23	33	3	1.14	18.0	sandstone
		C	61	66	26	8	1	1.40		
Artemisia tridentata/Festuca idahoensis h.t.										
272	854	A	10	58	14	28	19	1.05		
		B	66	47	20	33	59	2.68		
		Solum	76	48	19	33	54	2.47	8.8	igneous
		C	25	30	30	40	15	1.56		
140	1,208	A	41	68	20	12	15	1.83		
		B	0	--	--	--	--	--		
		Solum	41	68	20	12	15	1.83	3.4	gneiss
		C	102	84	12	4	18	1.56		
46	1,618	A	54	32	33	35	3	0.84		
		B	30	39	32	18	22	1.21		
		Solum	84	34	37	29	10	0.97	8.4	igneous
		C	69	31	42	27	28	1.42		

C3. — Soil Chemical Properties

Chemical properties of soil solum for stands selected to span range in vegetetative production within eight important habitat types

Stand No.	Average Production	pH	Ca	Mg	Na	K	P	N	OM[1]	CEC[2]	C:N Ratio
	kg/ha		*- - - - - -Metric tons/hectare in solum- - - - - -*							*me/100g*	
Stipa comata/Bouteloua gracilis h.t.											
102	271	7.7	47.9	2.9	0.10	2.2	0.06	1.2	72	10.0	21:1
180	[illegible]	7.6	51.6	5.1	.35	1.2	.02	.6	137	17.7	29:1
[illegible]	949	7.6	36.0	2.8	.18	1.0	.02	1.0	87	14.4	23:1
[illegible] *spicatum/Bouteloua gracilis* h.t.											
[illegible]	483	7.0	4.3	.5	.05	.5	.02	.6	42	20.0	44:1
149	488	7.1	9.3	1.4	.08	1.1	.07	.6	62	17.1	34:1
179	867	7.1	52.1	2.4	.16	1.5	.04	.7	136	22.2	35:1
Agropyron spicatum/A. smithii h.t.											
83	762	6.9	12.6	.8	.01	.6	.07	2.0	61	20.5	18:1
248	900	7.0	9.7	.4	.07	.5	.04	1.8	68	17.5	22:1
Festuca scabrella/Agropyron spicatum h.t.											
232	998	6.8	49.0	8.6	1.07	2.4	.03	1.8	141	30.1	28:1
87	1,346	6.9	10.0	.6	.01	.4	.04	2.9	94	22.7	19:1
Festuca scabrella/Festuca idahoensis h.t.											
304	1,261	6.9	4.2	.7	.20	1.1	.02	1.8	120	15.8	31:1
372	1,597	7.1	18.7	1.0	.09	.9	.02	5.7	249	24.2	18:1
208	1,828	6.2	22.9	3.9	.21	3.6	.12	3.9	280	18.3	30:1
Festuca idahoensis/Agropyron spicatum h.t.											
27	734	7.4	41.9	1.8	.08	1.0	.01	2.3	153	25.1	25:1
105	834	6.5	17.5	3.3	.04	3.0	.50	2.4	138	12.5	19:1
23	1,375	6.8	13.4	2.3	.26	1.9	.04	1.0	127	15.2	51:1
28	1,449	7.2	55.4	2.1	.04	1.5	.01	3.7	197	28.8	22:1
Festuca idahoensis/Agropyron caninum h.t.											
125	1,338	6.5	4.5	.5	.03	1.1	.07	2.8	206	18.2	32:1
41	1,727	6.0	16.2	2.1	--	3.3	.09	4.9	259	18.9	27:1
56	1,874	6.0	71.3	11.5	.68	2.9	.20	4.1	247	31.7	24:1
Artemisia tridentata/Festuca idahoensis h.t.											
272	854	7.0	17.3	1.6	.06	1.6	.18	1.0	114	10.6	29:1
140	1,208	6.8	7.8	1.1	.02	1.1	.04	2.4	125	14.3	31:1
46	1,618	6.4	16.3	2.4	.16	2.9	.07	6.3	238	18.5	20:1

[1]Organic matter.
[2]Cation exchange capacity.

APPENDIX D

APPENDIX D —

COVER CLASS SUMMARIES BY HABITAT TYPES

Mean and range of ground cover, and number of species identified on 20x20 m sample areas; number of stands sampled in each habitat type are shown in parentheses following the habitat type name

Habitat type	Canopy cover Shrubs	Canopy cover Grass	Canopy cover Forbs	Bryophytes	Litter	Rock	Bare soil	Number of species
	- - - -	- - - -	- - - -	- Percent	ground cover -	- - - -	- - - -	
Stipa comata/Bouteloua gracilis h.t. (7)								
Mean	5	54	3	10	23	5	24	16
Range	0-13	27-65	1-12	5-16	3-63	1-10	12-34	8-32
STCO/BOGR, Agropyron smithii phase (19)								
Mean	6	67	11	14	55	4	9	25
Range	<120	35-90	2-44	<1-48	11-86	0-25	2-19	11-42
Agropyron spicatum/Bouteloua gracilis h.t. (8)								
Mean	7	35	7	13	20	18	14	20
Range	4-17	24-45	0-11	4-26	12-26	2-46	4-42	11-28
AGSP/BOGR, Liatris punctata phase (14)								
Mean	6	59	16	17	53	6	7	30
Range	<1-15	34-76	5-27	<1-53	15-86	<1-18	<1-21	19-38
Agropyron spicatum/Agropyron smithii h.t. (9)								
Mean	5	42	20	13	36	13	18	30
Range	0-13	27-56	4-66	2-73	17-68	<1-70	<132	17-42
AGSP/AGSM, Stipa viridula phase (7)								
Mean	8	49	21	9	44	17	9	35
Range	0-23	27-76	12-34	<1-14	18-82	1-63	1-23	28-44
Agropyron spicatum/Poa sandbergii (MONT.) h.t. (8)								
Mean	6	58	17	24	53	23	12	26
Range	0-24	42-69	3-31	<1-63	38-64	3-59	1-30	17-39
AGSP/POSAN (MONT.), *Stipa comata* phase (9)								
Mean	5	52	20	17	47	11	12	30
Range	<1-13	24-72	<1-44	1-59	14-81	<1-56	0-22	17-44
Festuca scabrella/Agropyron spicatum h.t. (25)								
Mean	2	67	30	21	62	5	5	35
Range	0-20	27-90	12-47	2-63	14-90	<1-23	0-24	20-52
FESC/AGSP, Stipa comata phase (21)								
Mean	7	66	21	14	65	5	5	36
Range	<1-57	39-94	<7-40	1-57	12-92	0-19	0-15	27-48
Festuca scabrella/Festuca idahoensis h.t. (17)								
Mean	1	80	27	16	72	1	1	33
Range	0-8	48-92	9-64	0-67	17-95	0-8	0-3	16-44
FESC/FEID, Geranium viscosissimum phase (12)								
Mean	2	75	47	22	68	3	1	40
Range	0-25	38-90	18-68	0-91	29-87	0-22	0-7	31-63

APPENDIX D (con.)

Habitat type	Canopy cover			Bryo-			Bare	Number of
	Shrubs	Grass	Forbs	phytes	Litter	Rock	soil	species
	- - - - - - - - - -	Percent ground cover	- - - - - - -					
FESC/FEID, Stipa richardsonii phase (15)								
Mean	2	87	32	12	78	<1	1	32
Range	0-14	69-95	6-69	<1-38	30-97	0-1	0-3	16-50
Festuca idahoensis/Agropyron smithii h.t. (10)								
Mean	3	67	33	14	64	5	3	27
Range	0-10	48-83	1-67	4-28	14-90	<1-18	<1-8	15-42
Festuca idahoensis/Agropyron spicatum h.t. (45)								
Mean	4	62	28	16	46	8	5	33
Range	0-15	25-86	10-55	<1-62	9-94	0-40	0-25	22-50
FEID/AGSP, Stipa occidentalis phase (15)								
Mean	1	69	48	8	55	5	2	38
Range	0-6	42-90	32-63	<1-34	14-88	<1-16	<1-7	17-54
Festuca idahoensis/Carex filifolia h.t. (4)								
Mean	<1	65	53	2	27	1	2	35
Range	0-2	56-76	43-59	<1-8	15-35	<1-2	<1-4	30-43
Festuca idahoensis/Stipa richardsonii h.t. (3)								
Mean	4	79	49	7	84	<1	1	35
Range	0-9	73-84	34-57	<1-19	83-85	<1	<1-2	31-42
Festuca idahoensis/Agropyron caninum h.t. (9)								
Mean	<1	73	55	3	52	2	5	35
Range	0-2	61-82	33-68	0-9	26-89	0-12	<1-13	29-41
FEID/AGCA, Geranium viscosissimum phase (7)								
Mean	<1	77	58	<1	51	<1	3	40
Range	0-2	65-89	39-72	0-1	35-94	<1	<1-6	28-46
Festuca idahoensis/Deschampsia caespitosa h.t. (8)								
Mean	<1	66	50	7	36	2	3	28
Range	0-<1	26-82	25-70	<1-19	18-84	0-7	0-14	20-35
Deschampsia caespitosa/Carex spp. h.t. (6)								
Mean	1	88	34	16	76	--	<1	19
Range	0-4	82-92	<1-57	8-26	23-92	--	0-<1	12-27
Artemisia arbuscula/Agropyron spicatum h.t. (3)								
Mean	20	42	17	5	40	23	15	23
Range	14-26	25-65	13-20	3-9	26-49	17-32	13-18	21-27
ARAR/AGSP, Stipa comata phase (3)								
Mean	26	24	6	25	23	21	20	23
Range	21-32	22-27	2-10	3-51	13-30	10-24	9-32	21-25
Artemisia arbuscula/Festuca idahoensis h.t. (2)								
Mean	14	60	36	28	46	15	5	34
Range	8-21	44-75	13-60	9-46	24-69	7-22	2-8	32-37

(con.)

APPENDIX D (con.)

Habitat type	Canopy cover			Bryo-			Bare	Number of
	Shrubs	Grass	Forbs	phytes	Litter	Rock	soil	species
	- - - - - - - - - -	Percent	ground	cover	- - - - - - - -			
Artemisia tridentata/Agropyron spicatum (MONT.) h.t. (6)								
Mean	18	41	6	9	42	32	11	21
Range	5-31	24-60	<1-18	2-19	16-66	4-62	2-19	12-31
Artemisia tridentata/Festuca scabrella h.t. (6)								
Mean	22	53	20	12	69	16	4	31
Range	6-35	28-79	13-28	5-23	44-84	<1-43	0-12	23-40
Artemisia tridentata/Festuca idahoensis (MONT.) h.t. (8)								
Mean	21	52	27	22	61	7	3	32
Range	5-44	20-78	5-62	11-56	23-82	<1-23	<1-9	17-42
ARTR/FEID (MONT.), *Geranium viscosissimum* phase (4)								
Mean	24	87	60	1	80	1	1	41
Range	4-41	74-92	55-67	<1-3	37-95	<1-2	<1-2	38-44
Artemisia tripartita/Festuca idahoensis (MONT.) h.t. (5)								
Mean	23	84	32	6	80	7	4	26
Range	12-31	78-94	13-46	0-17	64-96	0-25	<1-11	14-41
Rhus trilobata/Agropyron spicatum h.t. (4)								
Mean	25	49	9	2	55	53	10	22
Range	3-60	32-60	6-11	<1-3	39-69	29-74	<1-18	19-25
Rhus trilobata/Festuca idahoensis h.t. (1)								
Mean	16	45	16	53	56	4	1	45
Range	--	--	--	--	--	--	--	--
Potentilla fruticosa/Festuca scabrella h.t. (5)								
Mean	16	61	30	9	66	19	4	48
Range	10-31	48-73	20-42	<1-16	38-83	<1-55	<1-9	44-53
POFR/FESC, Danthonia intermedia phase (6)								
Mean	26	76	42	8	87	<1	<1	45
Range	8-61	60-94	19-67	0-43	80-97	0-1	0-<1	28-59
Potentilla fruticosa/Festuca idahoensis h.t. (4)								
Mean	11	78	49	10	78	5	1	35
Range	3-25	68-87	31-74	4-16	70-83	<1-14	<1-3	25-47
Purshia tridentata/Agropyron spicatum (MONT.) h.t. (1)								
Mean	2	60	22	14	77	39	6	21
Range	--	--	--	--	--	--	--	--
Purshia tridentata/Festuca scabrella h.t. (4)								
Mean	19	71	26	35	75	12	4	32
Range	9-28	63-77	14-36	6-74	69-82	7-17	<1-11	24-37
Cercocarpus ledifolius/Agropyron spicatum h.t. (1)								
Mean	27	17	3	26	35	45	8	24
Range	--	--	--	--	--	--	--	--
Sarcobatus vermiculatus/Agropyron smithii h.t. (1)								
Mean	8	54	1	1	52	<1	19	4
Range	--	--	--	--	--	--	--	--

APPENDIX E —

SPECIES CONSTANCY AND CANOPY COVER BY HABITAT TYPE

Each table gives the constancy and canopy cover for all habitat types and phases ithin a climax series. Tables show constancy (in paraentheses), and canopy cover veraged over all stands within a habitat type or phase. The number of stands sampled ppears in parentheses in the box heading under each habitat type or phase name.

E1. — *Stipa comata* Series

Species constancy (in parentheses) and canopy cover for important species in the *Stipa comata*/*Bouteloua gracilis* h.t. (*STCO/BOGR*), and in the *Agropyron smithii* phase (*AGSM*) of this habitat type

Species	*STCO/BOGR* h.t. -- (7 stands)		*AGSM* phase (19 stands)	
	- - - - - - Percent		- - - - - -	
Medium Shrubs				
Chrysothamnus nauseosus	(57)	p[1]	(16)	p
Chrysothamnus viscidiflorus	(14)	p	(5)	p
Low Shrubs				
Artemisia frigida	(71)	1	(95)	6
Eurotia lanata	(100)	p	(37)	p
Gutierrezia sarothrae	(100)	1	(79)	p
Opuntia polyacantha	(100)	2	(63)	p
Graminoids				
Agropyron dasystachyum	--		(28)	2
Agropyron smithii	--		(74)	6
Agropyron spicatum	(57)	p	(50)	p
Bouteloua gracilis	(86)	27	(100)	8
Calamagrostis montanensis	--		(58)	2
Carex filifolia	--		(84)	8
Carex stenophylla	(86)	8	(95)	3
Koeleria cristata	(29)	p	(79)	6
Oryzopsis hymenoides	(29)	p	(5)	p
Poa cusickii	--		(26)	1
Poa sandbergii	(57)	1	(63)	p
Sporobolus cryptandrus	(43)	1	--	
Stipa comata	(86)	25	(100)	33
Stipa viridula	--		(16)	1
Forbs				
Astragalus purshii	(57)	p	(21)	p
Chrysopsis villosa	(14)	p	(58)	p
Gaura coccinea	(14)	p	(63)	p
Hymenoxys acaulis	--		(32)	p
Lepidium spp.	(29)	p	--	
Liatris punctata	--		(74)	p
Lygodesmia juncea	--		(53)	p
Melilotus officinalis	--		(32)	p
Paronychia sessiliflora	--		(42)	1
Phlox hoodii	(43)	1	(84)	5
Senecio canus	--		(32)	p
Sphaeralcea coccinea	(100)	p	(89)	1
Taraxacum officinale	(29)	p	(42)	p
Thelesperma marginatum	--		(42)	p
Tragopogon dubius	(43)	p	(58)	p
Vicia americana	--		(26)	1

[1]p = present with less than 0.5 percent canopy cover.

E2. — *Agropyron spicatum* Series

Species constancy (in parentheses) and average canopy cover for important species in the following habitat types within the *Agropyron spicatum* series: *Agropyron spicatum/Bouteloua gracilis* h.t. (*AGSP/BOGR*), with *Liatris punctata* phase (*LIPUN*); *A. spicatum/Agropyron smithii* h.t. (*AGSP/AGSM*), with *Stipa viridula* phase (*STVI*); and *A. spicatum/Poa sandbergii* (MONT.) h.t. (*AGSP/POSAN*), with *Stipa comata* phase *(STCO)*

Species	*AGSP/BOGR*		*AGSP/AGSM*		*AGSP/POSAN*	
	--	*LIPUN*	--	*STVI*	*STCO*	--
	(8 stands)	(14 stands)	(9 stands)	(7 stands)	(9 stands)	(8 stands)
	Percent					
Medium Shrubs						
Artemisia cana			--	(29) p	--	--
[illegible]sia tridentata	(25) p[1]	(6) p	(22) p	(29) p	(22) p	(25) p
[illegible]thamnus nauseosus	(63) p	(21) p	(67) 1	(29) p	(33) p	(50) p
[illegible]	(44) p	(7) p	(33) p	--	(11) 1	(38) 1
[illegible]us scopulorum	-	--	--	(14) p	(22) p	(13) p
[illegible]	-	--	(11) p	(14) p	--	(25) 1
Rosa arkansana	(13) p	(21) 1	(11) p	(29) p	(22) p	(13) p
Low Shrubs						
Artemisia dracunculus	(50) p	(21) p	--	(14) p	(22) p	(25) p
Artemisia frigida	(100) 6	(100) 5	(89) 2	(100) 5	(89) 2	(88) 2
Eurotia lanata	--	(14) p	(11) p	--	(22) 1	--
Gutierrezia sarothrae	(100) 2	(64) p	(89) 1	(100) 3	(56) 1	(38) 2
Leptodactylon pungens	(11) p		--	--	--	--
Opuntia polyacantha	(75) 1	(57) p	(22) p	(57) p	(44) p	(38) p
Yucca glauca	(13) p	(21) p	--	--	-	-
Graminoids						
Agropyron dasystachyum		(14) p	(56) 2	(14) 3	--	--
Agropyron smithii	--	(21) 2	(44) 1	(86) 4	-	--
Agropyron spicatum	(100) 16	(100) 25	(100) 18	(100) 16	(100) 20	(100) 46
Aristida longiseta	-	(14) p	(11) p	(29) 1	(11) 1	(25) 1
Bouteloua gracilis	(100) 8	(100) 5	(22) p	(29) p	(22) p	--
Bromus japonicus	(11) p	(14) p	--	(14) p	--	--
Bromus mollis	--	(7) p	--	--	(11) p	(13) p
Bromus tectorum	(13) p	(21) p	(22) p	(57) p	(33) 1	(38) 1
Calamagrostis montanensis	-	(36) p	(44) p	(14) p	(11) 1	(13) 2
[illegible]	--	(71) 3	(11) 1	(29) 1	(22) 2	--
[illegible]	(88) 2	(86) 1	(78) 2	(86) 1		(13) p
Festuca idahoensis	--	--	(11) p	--	--	(13) p
Festuca octoflora	--			--	(22) p	(13) p
Festuca scabrella	-	--	(11) p	(14) p	(22) p	(25) p
Helictotrichon hookeri	--	--	(11) 2	-		--
Koeleria cristata	(63) 5	(100) 7	(100) 8	(100) 7	(89) 5	(75) 3
Muhlenbergia cuspidata	--	(29) 1	(11) p	--	--	-
Oryzopsis hymenoides	(13) p		--	--	(11) p	(38) 1
Poa cusickii	--	(36) 1	(67) 3	(57) 4	(11) p	(13) p
[illegible]	-	--	--	--	(22) p	(13) p
[illegible]ndbergii	(100) 2	(86) 1	(78) 3	(71) 3	(100) 3	(75) 8
[illegible]	(100) 8	(100) 11	(100) 6	(86) 4	(89) 19	--
Stipa viridula	--	(21) 2	--	(100) 6	(11) 1	--
Stipa spartea	---	-	-	--	(11) p	-

(Con.)

Species	AGSP/BOGR		AGSP/AGSM		[illegible]	
		LIPUN	--	STVI	STCO	--
	(8 stands)	(14 stands)	(9 stands)	(7 stands)	(9 stands)	(8 stands)
	Percent					
Forbs						
Achillea millefolium	--	(29) p	(44) p	(43) p	(56) 1	(75) 2
Agoseris glauca	--	(7) p	--	(29) p	--	(13) p
Allium cernuum	(11) p	(50) p	(67) 1	(29) p	(33) p	(25) p
Antennaria dimorpha	--	--	(22) p	(14) p	(22) p	(13) p
Antennaria parvifolia	(25) p	(7) p	(44) p	(14) p	(11) p	--
Antennaria rosea	(13) p	(29) p	(44) p	(28) p	(33) p	(38) p
Arabis holboellii	(25) p	(7) p	(44) p	(28) p	(33) p	(50) p
Arenaria congesta	--	(7) p	(22) p	(14) p	(11) p	(25) p
Artemisia ludoviciana	--	(29) 1	--	(43) 1	(11) p	--
Aster falcatus	--	(14) p	(11) p	(43) 1	(11) p	--
Aster scopulorum	(25) p	--	(11) p	(29) p	--	--
Astragalus drummondii	--	(7) p	(11) p	(29) p	(22) 1	--
Astragalus miser	--	--	--	--	(33) 1	(25) 1
Astragalus purshii	(13) p	(14) p	(44) p	(43) p	(56) 1	--
Balsamorhiza incana	--	--	--	(29) 1	--	--
Balsamorhiza sagittata	--	--	--	--	(44) 3	(25) 2
Besseya wyomingensis	--	(14) p	(11) p	(29) p	(11) p	(13) p
Cerastium arvense	--	(7) p	(22) p	(14) p	(22) 1	(13) p
Chrysopsis villosa	(38) p	(79) 1	(67) 1	(86) 3	(56) 2	(50) p
Cirsium undulatum	--	(29) p	(11) p	--	(33) p	(25) p
Collinsia parviflora	--	-	--	--	(11) p	(13) p
Collomia linearis	--	--	--	--	(11) p	(25) p
Comandra umbellata	--	(21) p	(22) p	(43) 1	(67) 1	(50) 1
Crepis occidentalis	--	(21) p	(33) p	(43) p	--	(25) p
Cryptantha celosioides	(11) p	(29) p	(22) p	(29) p	(56) p	--
Draba verna	--	-	--	--	(11) p	(50) 1
Epilobium minutum	--	--	--	--	(22) p	(25) 1
Erigeron caespitosus	--	(43) p	(44) p	(43) 1	(33) p	(13) p
Erigeron compositus	(25) p	--	(44) p	(29) 1	(44) p	(13) p
Erigeron filifolius	(38) p	(21) p	(22) p	(29) p	(22) p	--
Erigeron pumilis	-	(7) p	--	--	(22) p	(25) p
Eriogonum flavum	-	-	(22) p	(14) p	(22) p	(25) p
Eriogonum microthecum	(63) p	--	--	--	(22) p	(50) p
Eriogonum ovalifolium	--	(7) p	(11) p	(29) p	--	--
Gaillardia aristata	--	(21) p	--	--	(22) p	(25) p
Gaura coccinea	(38) p	(57) p	(22) p	(43) p	(56) p	(38) p
Geum triflorum	--	--	(33) p	-	--	(25) p
Hymenoxys acaulis	--	(19) p	(22) 1	(29) 1	(22) p	--
Lappula echinata	(13) p	--	--	--	--	--
Lappula redowskii	--	-	--	--	(11) p	(25) p
Lesquerella alpina	--	(14) p	(11) p	(29) p	(22) p	--
Lepidium spp.	(38) p	(21) p	(56) 1	(71) 1	--	(13) 1
Liatris punctata	-	(93) 1	(22) p	(43) p	(22) p	(13) p
Linum perenne	--	(29) p	(33) p	(14) p	(44) p	(13) p
Lithospermum ruderale	(13) p	(14) p	--	(14) p	(44) p	(25) p
Lomatium cous	--	(7) p	--	(14) p	(22) p	--
Lomatium triternatum	--	--	(11) p	--	--	(25) p
Lupinus sericeus	--	(7) p	(11) p	(43) p	(33) p	(63) 1
Lygodesmia juncea	(13) p	(21) p	--	(14) p	(22) p	--
Oxytropis besseyi	(25) p	(14) 1	--	(14) p	--	--
Oxytropis sericea	(13) p	(14) p	--	(14) p	(22) p	(13) 1

(con.)

Species	AGSP/BOGR (8 stands)	AGSP/BOGR ([illegible] stands)	AGSP/AGSM (9 stands)	AGSP/AGSM ([illegible] stands)	STCO (9 stands)	AGSP/POSAN (8 stands)
		- - - - - - - - - - - - Percent - - - - - - - - - - - -				
Forbs (con.)						
[illegible]		(14) p	(11) 1	(29) p	(11) p	
[illegible]	--				--	(25) p
Phlox hoodii	[illegible]	(93) [illegible]	(89) 6	(100) 7	(67) 3	[illegible] [illegible]
[illegible]	[illegible] p	[illegible] p	(11) p	(29) p	(11) p	(25) p
Polygonum douglasii	--	--	-	(29) p	--	
[illegible]		[illegible] p	(22) p	(29) p	-	-
[illegible]	--	[illegible] 1	--	(29) p	.	--
[illegible]	[illegible] p	--	(33) p		(11) p	--
[illegible]	[illegible] p	[illegible] p	(33) 1	(29) p	[illegible] p	(25) p
Solidago missouriensis	--	[illegible] p	--	(29) p	(11) p	--
[illegible]	(88) p	[illegible] p	(78) p	(86) p	(44) p	(25) p
[illegible]	[illegible] p	(50) p	(44) p	(29) p	(22) p	(38) p
[illegible]		(29) [illegible]	--			-
[illegible]	[illegible] p	(86) 1	(67) p	(100) 1	(89) p	(75) 1
[illegible]	--	(29) 1	--	(86) 3	--	(25) p

[illegible]resent with less than 0.5 percent canopy cover.

E3. — *Festuca scabrella* Series

Species constancy (in parentheses) and average canopy cover for important species in the following habitat types within the *Festuca scabrella* series: *Festuca scabrella/Agropyron spicatum* h.t. (*FESC/AGSP*), with *Stipa comata* phase (*STCO*); and *F. scabrella/Festuca idahoensis* h.t. (*FESC/FEID*), with *Geranium viscosissimum* (*GEVI*) and *Stipa richardsonii* (*STRI*) phases

Species	*FESC/AGSP*			*FESC/FEID*	
	STCO	--	--	*GEVI*	
	(21 stands)	(25 stands)	(17 stands)	(12 stands)	(15 stands)
Medium shrubs					
Rosa arkansana	(33) p[1]	(28) p	(18) p	(8) 1	(53) 1
[illegible]	(24) p	(12) p	--	--	--
Low Shrubs					
Artemisia campestris	(10) p	--	(6) p	--	--
Artemisia dracunculus	(24) p	(8) p	--	(25)	-
Artemisia frigida	(100) 3	(48) 1	(41) 1	(17) p	--
Gutierrezia sarothrae	(57) p	(16) p	--	--	-
Graminoids					
Agropyron caninum	(10) p	--	(65) 1	(25) p	(47) 1
[illegible]	--	--	(24) 1	--	--
Agropyron smithii	(33) 1	(12) p	(24) 1	(8) p	(7) p
Agropyron spicatum	(95) 19	(100) 12	(35) p	(100) 6	(47) [illegible]
Bouteloua gracilis	(48) 1	--	--	--	--
Bromus carinatus	--	--	(6) p	(25) p	(7) p
Bromus japonicus	(10) p	(4) p	--	--	-
Bromus mollis	--	(12) p	(6) p	(8) p	--
Bromus tectorum	(14) p	(36) p	(6) p	--	—
Calamagrostis montanensis	(10) p	(8) p	(41) p	--	—
Carex filifolia	(48) 1	(28) 1	(47) 2	(17) 1	(73) 10
Carex obtusata	(10) 1	(8) p	(47) 2	(42) 2	(20) 1
Carex petasata	(10) p	(20) p	(41) 1	(67) 1	(40) 1
Carex pennsylvanica	(22) 1	(2) p	(29) 2	(8) 1	(13) 2
Carex rupestris	--	--	(6) 1	(8) 1	(7) p
Carex scirpoidea	--	--	—	(8) p	(13) 1
Carex stenophylla	(57) 1	(36) 1	(24) 2	--	(13) 1
Carex vallicola	--	(8) p	(6) 1	--	(40) 2
Danthonia intermedia	--	(8) p	(41) 2	(67) 1	(93) 3
[illegible]	(14) p	--	(18) 4	--	-
Danthonia unispicata	(19) p	(16) p	(18) p	(25) p	--
Festuca idahoensis	(71) 11	(100) 19	(100) 15	(100) [illegible]	(93) 11
Festuca scabrella	(100) 28	(100) 34	(100) 54	(100) 34	(100) 59
Helictotrichon hookeri	(19) p	--	(18) p	(8) p	(7) p
Koeleria cristata	(100) 3	(96) 3	(94) 2	(100) 3	(100) 1
Muhlenbergia cuspidata	(33) 1	--	--	--	--
Poa cusickii	(48) p	(20) 1	(29) 1	--	--
Poa pratensis	(5) p	(24) 1	(12) p	(42) 4	(13) p
Poa sandbergii	(52) 1	(76) 3	(29) p	(50) 1	(20) p
Stipa comata	(71) 1	(4) p	--	--	-
Stipa occidentalis	--	(20) p	(35) p	(67) 4	(47) 1
Stipa richardsonii	--	(12) p	--	-	(93) 15
Stipa spartea	(19) p	(4) p	(18) 1	(8) [illegible]	--
Stipa viridula	(14) p	(8) p	--	(33) p	-

			FESC/FEID GEVI	
	(21 stands)	(25 stands)	(17 stands) (12 stands)	(15 stands)

	Percent									
Forbs										
Achillea millefolium	[illegible]	1	(100)	3	(94)	2	(100)	3	(100)	2
Agoseris glauca	[illegible]	p	(36)	p	(33)	2	(50)	1	(40)	p
	(76)	1	(44)	p	(11)	p	(75)	p	(33)	p
	--		--		(18)	p	(33)	p	(40)	p
	[illegible]	p	(12)	p	(24)	p	(17)	p	--	
	--		--		-		(8)	p	--	
	--		--		(12)	p	--		(7)	p
Anemone multifida	-		(8)	p	(12)	p	(17)	p	(7)	p
Anemone patens	--		[illegible]	p	(53)	p	(25)	p	(47)	1
Antennaria anaphaloides	--		(4)	p	-		(42)	1	--	
Antennaria parvifolia	[illegible]	1	[illegible]	p	(6)	p	(17)	p	(13)	1
Antennaria rosea	(48)	p	(96)	3	(81)	1	(83)	2	[illegible]	1
Arabidopsis thaliana	--		[illegible]	p	(24)	p	(42)	p	(27)	p
Arenaria congesta	[illegible]	1	(48)	1	(70)	2	[illegible]	2	(73)	2
Arnica fulgens	[illegible]	p	(20)	p	(24)	1	(33)	1	(13)	p
Arnica sororia	(10)	p	(44)	1	(6)	p	(33)	1	(7)	1
Artemisia ludoviciana	(57)	1	(12)	p	(24)	p	(25)	p	(33)	p
Aster falcatus	(19)	p	--		(12)	p	(8)	p	(7)	p
Aster integrifolius	--		--		(12)	1	--		(27)	1
Astragalus miser	--		[illegible]	1	(12)	p	(17)	p	(7)	p
Astragalus striatus	(29)	p	(4)	p	(24)	p	(8)	p	--	
Balsamorhiza incana	(19)	p	(4)	p	--		(8)	p	--	
Balsamorhiza sagittata	(5)	p	(40)	2	(6)	p	(33)	p	(7)	p
Besseya wyomingensis	(10)	p	(52)	1	(35)	1	(50)	1	(40)	p
Campanula rotundifolia	(10)	p	(24)	p	(76)	1	(83)	1	(47)	p
Castilleja lutescens	--		(44)	p	(6)	p	(17)	p	--	
Cerastium arvense	[illegible]	1	(60)	3	(94)	2	(75)	2	(40)	1
Chrysopsis villosa	(90)	1	(56)	1	(24)	p	(17)	p	(7)	p
Comandra umbellata	(57)	p	(20)	p	(12)	p	--		(7)	p
Erigeron caespitosus	(33)	p	(32)	p	(41)	p	(17)	p	(40)	1
Erigeron compositus	(19)	p	(32)	p	(12)	p	(17)	p	--	
Erigeron corymbosus	(23)	p	(32)	1	--		(17)	p	(7)	p
Erigeron speciosus	--		(8)	p	(12)	p	(67)	2	(13)	p
	--		--		(12)	p	(25)	1	(20)	p
	(29)	p	(24)	p	(24)	p	(75)	2	(87)	3
Gaillardia aristata	(57)	p	(48)	p	(65)	1	(50)	p	(27)	p
Galium boreale	(19)	p	(28)	p	(76)	2	(58)	1	(73)	3
Gaura coccinea	(57)	p	(16)	p	--		--		--	
Gentiana affinis	--		--		(18)	p	(8)	p	(33)	p
Geranium viscosissimum	(5)	p	(20)	p	--		(100)	6	(80)	4
	(43)	p	(60)	p	(88)	3	(83)	3	(80)	4
pp.	(5)	p	(28)	p	(24)	p	(33)	p	(60)	1
Hieracium albertinum	--		(32)	p	(6)	p	(42)	1	(27)	p
Hymenoxys acaulis	(23)	p	--		--		--		--	
Liatris punctata	(71)	1	(8)	p	--		--		--	
Lithospermum ruderale	(53)	p	(52)	p	(29)	p	(67)	1	(60)	p
	(5)	p	(68)	p	(12)	p	(75)	p	(27)	p
Lupinus sericeus	(57)	3	(72)	4	(65)	4	(58)	4	(33)	4
	--		(24)	p	--		(8)	p	(7)	p

(con.)

APPENDIX [illegible] (con.)

Species	FESC/AGSP STCO		FESC/AGSP				FESC/FEID			
	([illegible]21 stands)		([illegible] stands)		(17 stands)		([illegible] stands)		([illegible] stands)	
	Percent									
Forbs (con.)										
[illegible]	(10)	p	-	p	(12)	p	--	p	(7)	p
Oxytropis deflexa	--		-		--		(8)	p	--	
Oxytropis lagopus	(10)	p	(4)	p	-		--		--	
[illegible]	(19)	p	([illegible])	p	(6)	p	--		--	
[illegible]	(14)	p	--		--		--		--	
[illegible]	-		(12)	[illegible]	(29)	p	(33)	1	(53)	1
[illegible]	(29)	p	(4)	p	--		--		-	
[illegible]	(23)	1	(4)	p	--		--		--	
Phlox hoodii	(48)	1	(12)	p	([illegible])	1	(8)	p	-	
[illegible]	([illegible])	p	([illegible])	p	--		([illegible])	p	(53)	p
[illegible]	(10)	p	(44)	p	(35)	p	(100)		(93)	2
Potentilla hippeana	(29)	p	([illegible])	p	(35)	[illegible]	--		-	
Senecio canus	(38)	p	([illegible])	p	(12)	p	--		(7)	p
Solidago missouriensis	(57)	p	([illegible])	p	(46)	1	(42)	1	(33)	1
Taraxacum officinale	(33)	p	(68)	1	([illegible])	p	(42)	p	(40)	p
Thermopsis rhombifolia	(33)	1	(8)	p	(29)	p	-		--	
[illegible]	(71)	p	([illegible])	p	([illegible])	p	(42)	p	(20)	p
[illegible]	(43)	p	(12)	p	([illegible])	p	(17)	p	-	
[illegible]	(19)	p	(44)	p	(35)	p	(42)	p	(20)	p

[1]p = present with less than 0.5 percent canopy cover.

E4. — *Festuca idahoensis* Series

Species constancy (in parentheses) and average canopy cover for important species in the following habitat types within the *Festuca idahoensis* series: *Festuca idahoensis/Agropyron smithii* h.t. (*FEID/AGSM*); *F. idahoensis/Agropyron spicatum* h.t. (*FEID/AGSP*), with *Stipa occidentalis* phase (*STOC*); *F. idahoensis/Carex filifolia* h.t. (*FEID/CAFI*); *F. idahoensis/Stipa richardsonii* h.t. (*FEID/STRI*); *F. idahoensis/Agropyron caninum* h.t. (*FEID/AGCA*), with *Geranium viscosissimum* phase (*GEVI*); and *F. idahoensis/Deschampsia caespitosa* h.t. (*FEID/DECA*)

Species	*FEID/AGSM*		*FEID/AGSP*				*FEID/CAFI*		*FEID/STRI*		*FEID/AGCA*				*FEID/DECA*	
	-- (10 stands)		-- (45 stands)		*STOC* (15 stands)		-- (4 stands)		-- (3 stands)		-- (9 stands)		*GEVI* (7 stands)		-- (8 stands)	
	Percent															
Medium Shrubs																
Artemisia cana	[illegible]	p	(7)	p	--		--		--		--		--		--	
A. tridentata	(20)	p	(36)	[illegible]	(33)	p	(25)	p	--		--		(43)	p	--	
[illegible] *nauseosus*	[illegible]	p	[illegible]	p	--		--		--		--		--		--	
C. viscidiflorus	[illegible]	p	(40)	1	(20)	p	--		--		(11)	p	--		--	
Potentilla fruticosa	--		(4)	p	(7)	p	--		(33)	p	--		--		--	
Rosa arkansana	--		(16)	p	--		--		(67)	4	--		(14)	p	--	
Tetradymia canescens	(20)	p	(31)	p	--		--		--		--		--		--	
Low Shrubs																
Artemisia frigida	(90)	[illegible]	(84)	2	(53)	1	--		--		--		--		--	
Gutierrezia [illegible]	(10)	p	(31)	p	--		--		--		--		--		--	
Graminoids																
Agropyron caninum	--		(2)	p	(60)	2	(100)	1	(67)	3	(100)	9	(100)	11	(63)	3
[illegible]	(70)	9	(4)	p	(7)	p	--		(33)	1	--		(14)	1	--	
A. smithii	(40)	5	(20)	1	--		--		--		--		--		--	
A. spicatum	(50)	p	(100)	18	(100)	15	(75)	p	(33)	p	(22)	1	(43)	1	--	
[illegible]	--		--		--		(50)	p	--		(22)	1	--		(38)	2
[illegible]	(10)	p	(9)	p	--		--		--		--		--		--	
[illegible]	--		--		(13)	p	--		(33)	p	(44)	1	(57)	2	--	
[illegible]	--		--		(7)	p	--		--		(44)	1	(71)	3	(13)	1
[illegible]	--		--		(7)	p	--		(33)	1	(14)	2	(14)	2	--	
[illegible]	--		(2)	p	--		--		(33)	p	--		--		--	
B. mollis	--		[illegible]	p	--		--		--		--		--		--	
[illegible]	--		(22)	p	(7)	p	--		--		--		--		--	
Carex albonigra	--		--		--		--		--		--		--		(13)	4
C. capillaris	--		--		--		--		--		--		--		(25)	1
C. filifolia	(10)	1	(18)	p	(47)	1	(100)	8	--		(11)	p	--		(25)	p
C. haydeniana	(10)	p	--		--		--		--		--		--		(25)	2
C. hoodii	--		--		(7)	2	--		--		--		(14)	p	--	
C. obtusata	--		(4)	p	(27)	3	--		--		(22)	3	(29)	6	--	
C. pennsylvanica	--		[illegible]	p	(7)	p	--		--		--		(14)	5	--	
[illegible]	--		(2)	p	(60)	5	(100)	1	(67)	4	(78)	2	(100)	1	(63)	p
C. pl[illegible]	--		--		--		--		--		--		--		(13)	2
[illegible]	--		(2)	p	--		--		--		(11)	p	--		(13)	p
[illegible]	--		--		--		(50)	14	--		--		--		--	
[illegible]	--		--		--		--		(33)	2	--		--		(50)	5
[illegible]	--		--		--		--		--		(11)	p	(29)	p	--	
C. stenophylla	(50)	2	(60)	1	(27)	2	(50)	2	--		(56)	2	(71)	1	(25)	p
C. vallicola	--		--		--		--		--		(11)	1	--		--	

(con.)

APPENDIX E4 (con.)

Species	FEID/AGSM		[illegible]				FEID/CAFI		FEID/		FEID/AGCA				FEID/DECA	
	--		--		STOC		--		--		--		[illegible]		-	
	(10 stands)		(45 stands)		(15 stands)		(4 stands)		(3 stands)		(9 stands)		(7 stands)		stands)	
	Percent															
Graminoids (con.)																
Danthonia intermedia	--		(4)	p	(53)	4	(100)	10	(100)	6	(89)	15	(86)	4	(50)	5
[illegible]	(10)	1	(9)	p	--		--		--		--		--		--	
[illegible]	--		--		--		--		--		-		--		(100)	17
Festuca idahoensis	(100)	43	(100)	37	(100)	31	(100)	29	(100)	12	(100)	36	(100)	24	(100)	21
F. [illegible]	--		(9)	p	--		--		(33)	1	(11)	p	--		--	
[illegible]	--		--		--		--		--		-		--		(13)	p
J. tenuis	--		--		-		--		--		--		--		(13)	1
[illegible]	(100)	5	(98)	4	(93)	4	(50)	1	(100)	p	(100)	1	(100)	4	(38)	p
Luzula spicata	--		--		-		(50)	p	--		-		--		(75)	2
Melica bulbosa	--		--		(7)	p	--		--		--		(29)	1	--	
M. [illegible]	--		--		--		--		--		--		--		(13)	1
[illegible]	-		--		--		--		--		--		--		(63)	2
P. pratense	--		(9)	p	--		--		(33)	p	(11)	p	(29)	2	--	
Poa cusickii	(70)	4	(22)	1	(47)	1	--		(33)	p	--		--		-	
P. [illegible]	--		--		--		(50)	p	-		--		--		--	
P. interior	--		--		(7)	p	(50)	p	--		(33)	p	(43)	p	(38)	1
P. juncifolia	(30)	p	(4)	p	(33)	p	(25)	p	(67)	2	(22)	p	(86)	3	(25)	p
P. pratensis	(10)	p	(11)	p	--		--		(33)	p	-		(29)	5	-	
P. sandbergii	(30)	4	(80)	3	(47)	1	(75)	p	--		(33)	1	--		(38)	p
Stipa comata	(20)	p	(60)	3	(13)	p	--		--		--		--		--	
S. occidentalis	--		(7)	p	(100)	6	--		(100)	13	(100)	7	(86)	7	(13)	3
S. richardsonii	--		--		(13)	p	--		(100)	36	(22)	p	(43)	2	--	
S. viridula	--		(13)	p	--		--		(33)	1	--		--		--	
[illegible]	--		--		--		(25)	p	--		--		--		(50)	1
T. [illegible]	--		--		--		--		--		--		--		(25)	1
Forbs																
Achillea millefolium	(70)	1	(82)	1	(100)	3	(100)	4	(100)	5	(100)	5	(100)	6	(63)	3
Agoseris glauca	(50)	2	(49)	2	(100)	2	(100)	2	(33)	1	(100)	3	(86)	2	(50)	2
A. grandiflora	--		--		(7)	p	--		--		(22)	1	(43)	p	(13)	p
Allium cernuum	(60)	p	(73)	1	(67)	p	(25)	p	(33)	1	--		--		--	
Anaphalis margaritacea	--		--		(27)	p	(25)	1	--		(11)	p	(71)	p	(13)	1
Androsace septentrionalis	--		(7)	p	--		--		--		(22)	p	(57)	p	(25)	p
Anemone patens	--		(4)	p	(20)	p	(50)	p	(33)	p	--		(14)	p	--	
Antennaria rosea	(60)	1	(80)	2	(80)	3	(100)	7	(100)	p	(78)	1	(71)	p	(38)	1
Arabis drummondii	(10)	p	--		(13)	p	(50)	p	--		--		--		(25)	p
Arenaria congesta	(50)	1	(63)	1	(93)	3	(100)	4	(33)	1	(89)	2	(100)	1	(13)	p
Arnica fulgens	(20)	p	(17)	p	(33)	1	--		--		(22)	p	--		(13)	p
A. sororia	--		(2)	p	--		--		--		--		--		-	
Artemisia ludoviciana	(40)	3	(26)	1	(13)	1	--		(33)	p	--		--		—	
Aster alpigenus	--		--		--		—		--		--		--		(13)	1
A. campestris	--		(2)	p	(7)	p	--		(33)	1	--		(14)	p	--	
A. foliaceus	--		--		--		--		--		--		(14)	p	(38)	1
A. integrifolius	--		(2)	p	(27)	2	--		--		(22)	2	(29)	p	--	
Astragalus miser	--		(28)	1	(20)	p	(25)	p	(33)	4	(22)	p	(29)	p	--	
A. purshii	(40)	1	(30)	p	(13)	p	--		--		(11)	p	--		--	
Balsamorhiza incana	(20)	1	(2)	p	--		--		—		--		--		--	
B. sagittata	--		(33)	1	--		--		--		—		--		--	
Besseya wyomingensis	(30)	1	(24)	p	(60)	1	(75)	2	(33)	p	(44)	p	(57)	p	(25)	p

(con.)

Species	-- (10 stand)		FEID/AGSP -- (45 stands)		FEID/AGSP STOC (15 stands)		FEID/CAFI -- (4 stands)		FEID/ -- (3 stand)		FEID/AGCA -- (9 stands)		FEID/AGCA GEVI (7 stands)		FEID/D -- (8 stands)	
[illegible]	[illegible]	[illegible]	(7)	[illegible]	(20)	p	--		(33)	p	--		-		(13)	p
Calochortus spp.	(10)	p	(11)	p	(13)	p	—		(67)	p	--		--		--	
[illegible]	[illegible]	1	(22)	p	(80)	1	(75)	1	(100)	1	(78)	1	(71)	1	--	
Castelleja cervina	(10)		(13)	p	(13)	p	(25)	p	--		--		--		--	
[illegible]	--		--		--		(50)	p	--		-		--		(25)	p
Cerastium arvense	(50)	4	(47)	[illegible]	(80)	1	(100)	2	(33)	p	(78)	4	(57)	1	(50)	1
Chrysopsis villosa	(40)	2	(62)	1	(13)	p	--		(67)	3	--		(14)	p	--	
Clematis hirsutissima	(10)	1	[illegible]	p	(53)	1	--		--		(11)	p	(57)	p	--	
Collomia linearis	[illegible]	p	(13)	p	(3)	p	--		--		(44)	1	(86)	1	--	
[illegible]	(10)	p	(38)	p	--		--		--		--		--		--	
[illegible]	(10)	p	(24)	p	(47)	p	(50)	p	(33)	p	(67)	p	(57)	p	(25)	p
Erigeron caespitosa	(40)	1	[illegible]	2	(53)	1	(50)	p	-		--		--		(13)	p
E. compositus	--		(33)	p	(20)	p	--		--		(11)	p	--		(25)	1
E. corymbosus	--		(9)	p	(7)	p	-		(33)	p	(22)	p	(14)	p	(13)	p
[illegible]	(20)	p	(4)	p	(20)	p	--		--		--		--		-	
E. speciosus	--		[illegible]	p	(7)	p	--		(33)	2	(56)	3	(57)	2	(13)	p
[illegible]	--		(4)	p	(27)	p	--		--		(33)	1	(71)	2	—	
[illegible]	(10)	p	(16)	p	(47)	2	--		(33)	p	(56)	p	(71)	3	--	
[illegible]	--		--		(7)	p	(50)	p	--		(56)	p	(43)	p	--	
Frasera speciosa	(20)	p	(9)	p	(47)	p	(25)	p	--		(33)	p	(14)	p	--	
Gaillardia aristata	(70)	2	(53)	p	(73)	3	—		(67)	1	(33)	p	(29)	p	--	
Galium boreale	(20)	[illegible]	(9)	p	(67)	2	--		(67)	10	(11)	1	(14)	p	(13)	p
[illegible]	(20)	p	(29)	p	(7)	p	--		--		-		--		--	
Gentiana affinis	--		(2)	p	(20)	p	(100)	5	(33)	p	(33)	p	--		(13)	p
[illegible]	--		--		--		--		--		--		--		(25)	p
Geranium viscosissimum	--		--		(20)	p	—		(100)	8	(11)	p	(100)	14	(13)	p
Geum rossii	--		--		—		--		--		--		--		(25)	6
[illegible]	(30)	p	(38)	p	(73)	3	(100)	16	(67)	1	(89)	15	(100)	11	(25)	2
Heuchera spp.	(20)	p	(17)	p	(20)	p	--		(33)	p	(11)	p	(14)	p	--	
Hieracium albertinum	--		(2)	p	(7)	p	--		(33)	p	(11)	p	--		--	
Lepidium ssp.	(10)	p	(30)	p	--		--		--		--		--		(13)	p
[illegible]	(20)	p	(24)	p	(40)	p	--		(33)	p	(22)	p	(29)	p	--	
[illegible]	--		(27)	p	(7)	p	--		(33)	p	-		(14)	p	—	
[illegible]	--		(8)	p	(13)	p	(75)	p	--		(11)	p	--		--	
[illegible]	--		(10)	p	--		--		--		-		--		--	
[illegible]	--		-		--		(75)	1	--		(11)	1	(14)	p	(63)	3
[illegible]	(30)	1	(60)	3	(67)	5	(25)	1	(33)	1	(44)	3	(71)	4	--	
Mertensia oblongifolia	--		(4)	p	(7)	p	(25)	p	-		--		--		--	
Oxytropis lagopus	--		(13)	p	--		--		--		--		--		--	
O. besseyi	--		(10)	p	(7)	p			--		—		--		--	
[illegible]	--		(16)	p	(20)	p	(75)	1	—		(11)	p	(14)	p	--	
Pedicularis contorta	--		(2)	p	(40)	2	(50)	p	--		(11)	p	--		(25)	p
Penstemon procerus	--		--		(7)	1	(50)	1	--		(56)	1	(14)	p	(50)	1
Perideridia gairdneri	--		-		--		--		--		(11)	p	(71)	p	--	
[illegible]	[illegible]	5	(67)	3	(60)	4	--		(33)	p	(22)	1	--		(13)	p
P. longifolia	(10)	p	(24)	1	(20)	p	--		--		(22)	p	(14)	p	--	
[illegible]	(10)	1	(9)	p	(27)	1	(50)	3	(33)	p	(56)	1	(14)	p	(13)	p
Polygonum bistortoides	-		(2)	p	(40)	p	(100)	3	--		(33)	p	(14)	p	(88)	3
P. douglasii	(10)	p	(2)	p	--		--		--		(44)	p	(71)	1	--	

(con.)

APPENDIX [illegible] (con.)

Species	FEID/AGSM		FEID/AGSP		STOC		FEID/CAFI		[illegible]		[illegible]		[illegible]		FEID/DECA	
	([illegible] stands)		(45 stands)		(15 stands)		(4 stands)		(3 stands)		(9 stands)		(7 stands)		(8 stands)	
	Percent															
Forbs (con.)																
[illegible]	--		--		([illegible])	p	--		([illegible])	1	(22)	p	[illegible]		[illegible]	
[illegible]	--		--		(7)	p	(75)	2	(33)	1	(44)	p	(14)	p	[illegible]	[illegible]
[illegible]	--		([illegible])	p	(33)	p	(75)	2	(67)	1	([illegible])	[illegible]	(100)	11	(25)	1
P. [illegible]	(10)	p	(16)	p	(40)	p	--		(33)	p	--		(14)	p	--	
[illegible]	--		--		(7)	p	(25)	p	--		(22)	p	--		--	
[illegible]	(10)	p	(29)	p	([illegible])	p	([illegible])	p	--		(11)	p	--		[illegible]	p
[illegible]	(20)	p	(22)	p	(13)	p	--		--		--		--		--	
[illegible]	--		--		--		--		--		(22)	p	(29)	p	--	
[illegible]	--		([illegible])	p	([illegible])	p	(25)	1	--		(22)	p	(14)	p	--	
Solidago [illegible]	(20)	p	(27)	p	(27)	p	(25)	p	(67)	1	(33)	[illegible]	(14)	p	(25)	1
Taraxacum officinale	([illegible])	1	(67)	p	(80)	1	--		(67)	1	(78)	p	(86)	p	--	
Tragopogon dubius	(40)	p	(67)	1	(13)	p	--		(67)	p	(11)	p	(14)	p	--	
[illegible] spp.	--		(2)	p	--		--		--		(33)	2	(14)	p	([illegible])	[illegible]
Vicia americana	(20)	1	(16)	p	(13)	1	--		(33)	1	--		--		--	
[illegible]	(20)	1	(42)	p	(53)	p	(25)	p	(33)	p	(22)	p	--		--	

[1]p = present with less than 0.5 percent canopy cover.

E5. — *Deschampsia caespitosa* Series

Species constancy (in parentheses) and average canopy cover for important species in the *Deschampsia caespitosa/Carex* spp. h.t. (*DECA/Carex*)

Species	*DECA/CAREX* -- (6 stands)
	Percent
Low Shrubs	
[illegible]	(17) 1
Graminoids	
Agrostis diegoensis	(17) 4
[illegible]	(17) 1
A. idahoensis	(33) p
[illegible]	(33) 1
Alopecurus pratensis	(33) 3
[illegible]	(17) p[1]
[illegible]	(33) 14
C. parryana	(50) 10
C. rupestris	(17) 7
[illegible]	(33) 6
Danthonia intermedia	(83) 5
Deschampsia caespitosa	(100) 45
[illegible]	(17) 1
J. hallii	(33) 3
[illegible]	(17) 1
[illegible]	(17) 1
Luzula campestris	(33) p
[illegible]	(83) 2
Poa pratensis	(33) p
Trisetum wolfii	(33) 2
Forbs	
Achillea millefolium	(17) 1
Antennaria corymbosa	(67) 6
Arnica chamissonis	(17) 1
Aster foliaceus	(17) 2
Camasia quamash	(17) 3
Erigeron speciosus	(50) 5
Gentiana affinis	(33) p
Pedicularis gronenlandica	(33) p
Polygonum bistortoides	(83) 1
Potentilla arguta	(17) p
P. diversifolia	(33) p
P. gracilis	(83) 1
[illegible]	(17) p
R. salicifolius	(17) 1
Senecio intergerrimus	(17) 3
S. lugens	(33) p
[illegible]	(17) 3
Trifolium spp.	(33) p
Veronica wormskjoldii	(33) 1

[1] p = present with less than 0.5 percent canopy cover.

E6. — *Artemisia arbuscula* Series

Species constancy (in parentheses) and average canopy cover for important habitat types within the *Artemisia arbuscula* series: *Artemisia arbuscula/Agropyron spicatum* h.t. (*ARAR/AGSP*), with *Stipa comata* phase (*STCO*); and *A. arbuscula/Festuca idahoensis* h.t. (*ARAR/FEID*)

Species	*ARAR/AGSP*				*ARAR/FEID*	
	STCO		-		-	
	(3 stands)		(3 stands)		(2 stands)	
	Percent					
Medium Shrubs						
Artemisia arbuscula	(100)	22	(100)	7	(100)	[illegible]
A. tridentata	--		(100)	12	(100)	p
Chrysothamnus nauseosus	--		--		(50)	p
C. viscidiflorus	--		(33)	p	(50)	1
Tetradymia canescens	(33)	p[1]	--		(50)	1
Low Shrubs						
Artemisia frigida	(67)	1	--		(100)	p
Eurotia lanata	(33)	p	--		(50)	p
Gutierrezia sarothrae	(67)	4	(33)	p	--	
Leptodactylon pungens	(33)	p	--		--	
Opuntia polyacantha	(100)	p	(67)	p	--	
Graminoids						
Agropyron spicatum	(100)	14	(100)	23	(100)	24
Aristida longiseta	(33)	p	--		--	
Bouteloua gracilis	(67)	p	--		--	
Carex filifolia	(33)	p	(33)	p	--	
C. pennsylvanica	--		(33)	1	--	
C. stenophylla	(33)	p	--		(100)	p
Festuca idahoensis	--		--		(100)	31
Hesperochloa kingii	--		(33)	10	--	
Koeleria cristata	(100)	4	(100)	8	(100)	9
Oryzopsis hymenoides	(67)	1	--		--	
Poa cusickii	--		--		(50)	2
P. sandbergii	(100)	1	(100)	2	(50)	3
Stipa comata	(100)	3	--		(50)	p
S. occidentalis	--		--		(50)	p
Forbs						
Achillea millefolium	--		(33)	p	(50)	2
Agoseris glauca	--		--		(50)	1
Allium cernuum	(67)	p	(67)	p	(100)	p
Anaphalis margaritacea	--		--		(50)	1
Androsace septentrionalis	--		--		(50)	p
Antennaria rosea	--		(33)	p	(100)	12
Arabis holboellii	(33)	p	--		(50)	p
A. microphylla	--		(67)	p	--	
Arenaria congesta	--		(67)	p	(50)	p
Aster scopulorum	--		--		(50)	p
Astragalus drummondii	(33)	p	--		--	
A. playtropis	(33)	p	--		--	
A. purshii	(67)	p	(67)	p	--	
Besseya wyomingensis	--		--		(50)	p
Bupleurum americanum	--		--		(50)	p

(con.)

[1]p = present with less than 0.5 percent canopy cover.

Species	ARAR/AGSP				ARAR/FEID	
	STCO		--		--	
	(3 stands)		(3 stands)		(2 stands)	
	- - - - - - - - - - - Percent - - - - - - - - - - -					
Forbs						
Castilleja angustifolia	--		(67)	2	--	
C. [illegible]	--		--		(50)	p
C. linariaefolia	--		(33)	p	--	
C. pallescens	--		(33)	p	--	
Clematis hirsutissima	--		--		(50)	3
Comandra umbellata	(67)	p	(33)	p	(50)	p
Crepis occidentalis	--		(67)	1	(50)	p
Cryptantha celosioides	(33)	p	--		(50)	p
Delphinium occidentale	--		--		(50)	p
Descurainia richardsonii	(33)	p	--		--	
Dodecatheon conjugens	--		--		(50)	p
Draba oligosperma	(33)	p	--		--	
Erigeron caespitosa	--		(67)	p	--	
E. compositus	--		--		(100)	2
E. corymbosus	--		(37)	p	--	
E. divergens	--		(33)	p	--	
E. filifolius	(33)	p	--		--	
E. ochroleucus	--		(67)	p	--	
E. tweedyi	(33)	p	--		(50)	1
Eriogonum microthecum	(33)	p	--		--	
E. ovalifolium	(33)	p	(33)	p	--	
E. umbellatum	(33)	p	--		--	
Frasera speciosa	--		--		(50)	1
Geum triflorum	--		--		(50)	p
Haplopappus acaulis	(33)	p	(67)	p	--	
Hymenoxys acaulis	(33)	p	(67)	p	--	
Lesquerella alpina	(67)	p	(33)	p	(50)	p
Lewisia rediviva	--		(33)	p	--	
Liatris punctata	(33)	p	--		--	
Linum perenne	(67)	p	(100)	1	(100)	p
Lithospermum incisum	--		--		(50)	p
L. ruderale	(33)	p	--		--	
Oxytropis sericea	--		--		(50)	7
Paronychia sessiliflora	(33)	1	--		--	
Pedicularis contorta	--		--		(50)	1
Penstemon aridus	--		(33)	p	--	
Phlox albomarginata	(33)	p	--		--	
P. hoodii	(67)	p	(100)	9	(100)	4
P. longifolia	--		--		(50)	1
Potentilla gracilis	--		--		(50)	p
P. pennsylvanica	--		(33)	p	--	
Sedum lanceolatum	(33)	p	(33)	p	(50)	p
Senecio canus	(67)	p	(33)	p	(50)	1
S. pauperculus	--		--		(50)	2
Sphaeralcea coccinea	(33)	p	--		--	
Taraxacum officinale	--		(33)	p	(100)	p
Townsendia mensana	--		--		(50)	p
T. [illegible]	--		--		(50)	p
Tragopogon dubius	(33)	p	--		--	

E7. — *Artemisia tridentata* Series

Species constancy (in parentheses) and average canopy cover for important species in the following habitat types within the *Artemisia tridentata* series: *Artemisia tridentata/Agropyron spicatum* (MONT.) h.t. (*ARTR/AGSP*); *A. tridentata/Festuca scabrella* h.t. (*ARTR/FESC*); and *A. tridentata/Festuca idahoensis* (MONT.) h.t. (*ARTR/FEID*), with *Geranium viscosissimum* phase (*GEVI*)

Species	*ARTR/AGSP*	*ARTR/FESC*	*ARTR/FEID*	
	--	--	--	*GEVI*
	(6 stands)	(6 stands)	(8 stands)	(4 stands)
	- - - - - -	- - - - - - *Percent*	- - - - - -	- - - - - -
Medium Shrubs				
Amelanchier alnifolia	--	(50) p	--	--
Artemisia tridentata	(100) 15	(100) 21	(100) 18	(100) 23
Chrysothamnus nauseosus	(33) p[1]	(17) p	(25) p	--
C. viscidiflorus	(17) p	--	(75) 1	--
Rosa arkansana	--	(50) p	--	--
Tetradymia canescens	(17) p	(17) p	(25) p	--
Low Shrubs				
Arctostaphylos uva-ursi	--	(17) 1	--	--
Artemisia frigida	(83) 2	(33) p	(63) 1	--
Gutierrezia sarothrae	(83) 2	--	(13) p	--
Opuntia polyacantha	(67) p	--	(13) p	--
Graminoids				
Agropyron canium	--	--	--	(100) 12
A. dasystachyum	--	--	(13) 2	--
A. smithii	--	(17) 1	(13) p	--
A. spicatum	(100) 32	(83) 6	(75) 5	(100) 2
Bouteloua gracilis	(83) 1	(33) p	--	--
Bromus carinatus	--	--	--	(75) 13
B. ciliatus	--	--	(13) 1	--
Calamagrostis rubescens	--	--	--	(50) 2
Carex obtusata	--	--	(25) 2	--
C. petasata	(17) p	(17) 1	(25) 1	(25) p
C. pennsylvanica	--	--	(25) 1	--
C. raynoldsii	--	--	--	(75) 9
C. stenophylla	(50) 1	(17) p	--	(25) p
Danthonia intermedia	--	(33) 2	(38) p	(100) 16
Festuca idahoensis	--	(83) 16	(100) 39	(100) 36
F. scabrella	--	(100) 25	--	--
Koeleria cristata	(83) 5	(100) 1	(88) 4	(100) 3
Poa cusickii	--	(83) p	(25) p	--
P. juncifolia	--	(17) p	--	(100) 6
P. sandbergii	(83) 2	(17) p	(88) 1	--
Stipa comata	(83) 2	--	(38) 1	(25) 2
S. occidentalis	--	--	(38) p	(100) 14
S. richardsonii	--	(17) 3	(25) p	(25) p
Forbs				
Achillea millefolium	(17) p	(100) 1	(75) 1	(100) 8
Agoseris glauca	--	(17) p	(63) 1	(100) 1
Allium cernuum	(67) p	(83) p	(63) 1	--
Anaphalis margaritacea	--	(17) p	--	(50) p
Androsace occidentalis	--	--	--	(50) p

(con.)

Species	ARTR/AGSP		ARTR/FESC		ARTR/FEID			
	--		--		--		GEVI	
	(6 stands)		(6 stands)		(8 stands)		(4 stands)	
	Percent							
Forbs (con.)								
Androsace septentrionalis	--		--		(25)	p	(25)	p
Anemone patens	--		--		--		(50)	p
Antennaria parvifolia	(17)	p	(17)	p	(13)	2	(75)	1
A. rosea	(33)	p	(83)	4	(75)	4	(25)	p
Arabidopsis thaliana	--		--		(25)	p	(75)	p
Arabis holboellii	(33)	p	(33)	p	(13)	p	--	
Arenaria congesta	(17)	p	(83)	2	(50)	p	(100)	3
Artemisia ludoviciana	--		(50)	1	(13)	p	--	
Aster campestris	--		--		--		(75)	2
A. falcatus	--		(50)	p	--		--	
Astragalus drummondii	(17)	p	(17)	p	(25)	1	--	
A. miser	--		(17)	2	(25)	1	(75)	2
A. purshii	(33)	p	(33)	p	(13)	p	--	
Balsamorhiza sagittata	--		(33)	p	(13)	p	(50)	p
Besseya wyomingensis	--		--		(50)	p	--	
Campanula rotundifolia	--		(50)	p	(13)	p	(100)	1
Cerastium arvense	--		(67)	1	(25)	1	(50)	2
Chrysopsis villosa	(17)	p	(17)	p	(50)	1	--	
Clematis hirsutissima	--		(33)	p	(13)	1	(25)	p
Collomia linearis	--		(17)	p	--		(100)	p
Comandra umbellata	(17)	p	(50)	p	(50)	p	--	
Crepis occidentalis	(50)	p	(33)	p	(13)	p	--	
Cymopterus bipinnatus	--		--		(25)	1	--	
Delphinium bicolor	--		--		(25)	p	--	
Dodecatheon conjugens	--		--		(38)	p	(100)	p
Erigeron caespitosus	(50)	p	(33)	1	(13)	p	--	
E. compositus	(50)	p	(33)	p	(50)	1	--	
E. filifolius	(33)	p	(17)	p	--		--	
Erigonum umbellatum	(17)	p	(67)	1	(38)	p	(100)	10
Erysimum asperum	--		--		--		(75)	p
Fragaria virginiana	--		(33)	p	--		(25)	p
Geranium viscosissimum	--		(33)	p	--		(100)	5
Geum triflorum	(17)	p	(17)	1	(75)	2	(100)	10
Haplopappus acaulis	(17)	p	--		(38)	1	--	
Helianthella uniflora	--		--		--		(100)	7
Heuchera cylindrica	--		--		(25)	p	--	
Lesquerella alpina	--		(50)	p	(13)	p	--	
Linum perenne	(17)	p	(50)	p	(13)	p	(75)	1
Lithospermum ruderale	(33)	p	(33)	p	(25)	p	--	
Lomatium triternatum	(17)	p	(17)	p	--		(75)	1
Lupinus sericeus	(33)	1	(50)	2	(50)	3	(25)	p
L. wyethia	--		--		--		(75)	1
Mertensia obligifolia	--		--		(25)	p	--	
Oxytropis besseyi	(33)	1	--		--		--	
[illegible]	(33)	p	--		(13)	p	--	
Phlox hoodii	(33)	1	(67)	p	(50)	2	--	
P. longifolia	--		(17)	p	(13)	p	(50)	3
P. multiflora	--		--		(50)	p	(25)	2
Polygonum douglasii	--		--		--		(75)	1

(con.)

APPENDIX E7 (con.)

Species	ARTR/AGSP		ARTR/FESC		ARTR/FEID			
			--		--		GEVI	
	(6 stands)		(6 stands)		(8 stands)		(4 stands)	
	- - - - - - - - - - - - - Percent - - - - - - - - - - - -							
Forbs (con.)								
Potentilla arguta	--		(17)	p	(13)	p	(75)	4
P. glandulosa	--		--		--		(25)	1
P. gracilis	--		(50)	1	--		(100)	3
P. pennsylvanica	(17)	p	(33)	p	(13)	p	--	
Sedum lanceolatum	--		--		(63)	p	--	
Senecio canus	(33)	p	(33)	p	(38)	p	--	
Silene parryii	--		--		(13)	1	(75)	p
Taraxacum officinale	(17)	p	(67)	p	(75)	p	(50)	p
Tragopogon dubius	(50)	p	(67)	p	(38)	p	--	
Vicia americana	--		(33)	p	--		(25)	p
Zigadenus venenosus	--		--		(38)	p	(25)	p

[1]p = present with less than 0.5 percent canopy cover.

E8. — *Artemisia tripartita* Series

Species constancy (in parentheses) and average canopy cover for important species in the *Artemisia tripartita/Festuca idahoensis* h.t. (MONT.) (*ARTRI/FEID*)

Species	*ARTRI/FEID* -- (5 stands)
	- - - - - - - - - *Percent* - - - - - - - - -
Medium Shrubs	
Artemisia tridentata	(60) 1
A. tripartita	(100) 12
Chrysothamnus viscidiflorus	(100) 4
Tetradymia canescens	(80) 3
Low Shrubs	
Artemisia frigida	(80) 1
Gutierrezia sarothrae	(40) p[1]
Graminoids	
Agropyron caninum	(60) 7
A. dasystachyum	(60) 7
A. spicatum	(20) 7
Calamagrostis montanensis	(100) 8
Carex stenophylla	(80) 1
Festuca idahoensis	(100) 56
Koeleria cristata	(100) 5
Poa cusickii	(60) 5
P. sandbergii	(40) 1
Stipa comata	(20) 10
Forbs	
Achillea millefolium	(100) p
Agoseris glauca	(40) p
Androsace septentrionalis	(40) p
Antennaria rosea	(60) 2
Arabidopsis thaliana	(40) p
Comandra umbellata	(40) 1
Erigeron compositus	(60) p
Eriogonum umbellatum	(60) p
Geum triflorum	(40) p
Lepidium spp.	(40) p
Lupinus sericeus	(60) 13
Phlox hoodii	(100) 5
Sedum lanceolatum	(40) p
Taraxacum officinale	(80) 1
Tragopogon dubius	(40) p

[1]p = present with less than 0.5 percent canopy cover.

E9. — *Potentilla fruticosa* Series

Species constancy (in parentheses) and average canopy cover for important species in the following habitat types within the *Potentilla fruticosa* series: *Potentilla fruticosa/Festuca scabrella* h.t. (*POFR/FESC*), with *Danthonia intermedia* phase (*DAIN*); and in the *P. fruticosa/Festuca idahoensis* h.t. (*POFR/FEID*)

Species	*POFR/FESC* -- (5 stands)	*POFR/FESC* *DAIN* (6 stands)	*POFR/FEID* -- (4 stands)
	- - - - - - - - - -	*Percent*	- - - - - - - - - -
Medium Shrubs			
Potentilla fruticosa	(100) 13	(100) 14	(100) 10
Rosa arkansana	(20) p[1]	(50) 1	--
Rosa woodsii	(20) p	(17) p	--
Low Shrubs			
Arctostaphylos uva-ursi	(20) 1	(67) 11	--
Artemisia frigida	(100) 2	--	--
A. campestris	(60) 1	--	--
Gutierrezia sarothrae	(80) p	--	--
Juniperus horizontalis	(20) p	(33) 1	--
Graminoids			
Agropyron caninum	(20) p	(100) 2	(50) 2
A. dasystachyum	(20) 1	(33) 1	--
A. smithii	(20) 1	--	--
A. spicatum	(80) 9	(17) p	(25) p
Agrostis scabra	--	(33) p	(50) 1
Bouteloua gracilis	(40) 1	--	--
Bromus carinatus	--	(33) p	--
B. ciliatus	--	(17) p	--
Calamagrostis purpurascens	--	(17) p	(75) 1
Calamovilfa longifolia	(40) p	--	--
Carex filifolia	(40) 1	(17) p	(25) 4
C. hoodii	--	(17) p	--
C. obtusata	(40) p	(67) 6	(75) 8
C. parryana	--	--	(25) 3
C. pennsylvanica	(20) p	(33) p	--
C. petasata	--	(67) 1	(25) p
C. practicola	--	--	(25) 1
C. raynoldsii	--	(17) 1	--
C. scirpoidea	(80) 5	--	--
C. stenophylla	(20) p	(17) 1	(25) 4
C. vallicola	--	(17) p	--
Danthonia intermedia	--	(100) 5	(75) 18
D. parryi	(40) 13	--	--
Festuca idahoensis	(80) 5	(100) 16	(100) 40
F. scabrella	(100) 17	(100) 48	(25) p
Helictotrichon hookeri	(60) p	(83) p	(50) p
Koeleria cristata	(100) 4	(100) 1	(75) 1
Luzula spicata	--	--	(50) 1
Muhlenbergia cuspidata	(60) p	--	--
M. richardsonii	(80) 1	--	--
Phleum pratense	(60) p	--	--
Poa grayana	--	--	(25) p
P. interior	--	(17) p	(25) 2
P. juncifolia	--	--	(25) 2

(con.)

Species	POFR/FESC -- (5 stands)		POFR/FESC DAIN (6 stands)		POFR/FEID -- (4 stands)	
	- - - - - -	- - - - - -	Percent	- - - - - -	- - - - - -	- - - - - -
Graminoids (con.)						
[illegible]	--		--		(25)	1
P. pratensis	(60)	p	(83)	6	(25)	p
P. [illegible]	--		--		(25)	1
P. sandbergii	(40)	1	(17)	p	--	
Stipa occidentalis	(40)	p	(33)	p	(25)	p
S. richardsonii	(40)	1	--		(25)	2
S. viridula	--		(33)	p	--	
Forbs						
Achillea millefolium	(100)	1	(100)	2	(100)	5
Agoseris glauca	(60)	p	(100)	3	(75)	3
Allium cernuum	(100)	1	(67)	p	(50)	1
Anaphalis margaritacea	--		(33)	p	(25)	1
Anemone multifida	(20)	p	(33)	p	(25)	p
A. patens	(60)	p	(67)	p	--	
Antennaria anaphaloides	--		(33)	p	(25)	1
A. parvifolia	(80)	2	(17)	p	(25)	p
A. rosea	(20)	p	(50)	p	(75)	1
Arabis holboellii	(40)	p	--		--	
Arenaria congesta	(40)	p	(67)	p	(100)	3
Arnica fulgens	--		(17)	p	(25)	p
A. sororia	--		(33)	p	--	
Artemisia ludoviciana	--		(33)	p	--	
Aster intergrifolius	(60)	p	(33)	p	--	
Astragalus miser	--		(17)	p	(25)	p
A. purshii	(40)	p	--		--	
Besseya wyomingensis	(20)	p	(67)	p	(100)	4
Bupleurum americanum	(20)	p	(67)	p	(25)	p
Campanula rotundifolia	(80)	1	(100)	1	(100)	2
Cerastium arvense	(60)	1	(100)	2	(75)	4
Chrysopsis villosa	(80)	1	(33)	p	--	
Clematis hirsutissima	--		(33)	p	(25)	p
Comandra umbellata	(60)	p	(17)	p	--	
Cryptantha celosioides	(20)	p	--		(25)	p
Dodecatheon conjugens	(20)	p	(100)	p	(75)	p
Douglasia montana	--		--		(50)	p
Erigeron caespitosus	(60)	1	--		(50)	p
E. compositus	(40)	p	--		--	
E. corymbosus	(20)	p	(17)	p	--	
E. filifolia	(20)	p	--		(25)	1
E. simplex	--		--		(25)	p
E. speciosus	--		(50)	3	--	
Eriogonum umbellatum	(20)	p	(17)	p	(25)	p
Fragaria virginiana	(20)	p	(83)	p	--	
Frasera speciosa	(40)	p	(17)	p	(75)	1
Gaillardia aristata	(100)	2	(83)	p	(25)	p
Gulium boreale	(100)	3	(100)	3	(50)	2
Gentiana affinis	(20)	p	--		(25)	2
Geranium viscosissumum	--		(50)	1	--	

(con.)

Appendix E9 (con.)

Species	POFR/FESC -- (5 stands)		POFR/FESC DAIN (6 stands)		POFR/FEID -- (4 stands)	
	- - - - - - - - - - - -		Percent		- - - - - - - - - - - -	
Forbs (con.)						
Geum triflorum	(60)	p	(50)	2	(75)	6
Haplopappus acaulis	(40)	p	--		--	
Hedysarum spp.	(40)	p	(67)	1	--	
Heuchera spp.	--		--		(75)	p
Hymenoxys acaulis	(40)	p	--		--	
Iris missouriensis	(40)	p	(33)	p	--	
Lesquerella alpina	(40)	p	--		--	
Liatris punctata	(40)	p	--		--	
Linum perenne	(80)	1	(33)	p	--	
Lithospermum ruderale	--		(50)	p	--	
Lupinus sericeus	(20)	p	(67)	7	(25)	1
Lupinus spp.	--		(17)	p	(25)	1
Lychnis drummondii	--		--		(25)	p
Monarda fistulosa	--		(50)	1	--	
Oxytropsis campestris	--		(17)	p	(25)	p
O. sericea	(80)	1	(17)	p	(25)	p
O. viscida	(20)	1	--		--	
Pedicularis contorta	--		--		(25)	1
Penstemon eriantherus	(40)	1	--		--	
P. procerus	--		(33)	p	(50)	1
Petalostemon purpurpeum	(60)	p	--		--	
Phlox hoodii	(40)	p	(33)	2	(25)	1
P. kelseyi	(40)	3	--		--	
P. muscoides	(40)	p	--		--	
P. pulvinata	--		--		(25)	2
Plantago tweedyi	(40)	1	--		--	
Polygonum bistortoides	--		(33)	p	(75)	1
Potentilla gracilis	(20)	p	(83)	3	(100)	2
P. hippiana	(40)	p	(33)	p	--	
Sedum lanceolatum	--		(17)	p	(100)	1
Senecio canus	(100)	2	(17)	p	--	
S. megacephalus	(40)	1	--		(25)	1
Solidago missouriensis	(100)	1	(83)	1	(25)	p
Taraxacum officinale	(40)	p	(50)	1	(50)	p
Thermopsis rhombifolia	(40)	p	--		--	
Tragopogon dubius	(60)	p	(33)	p	--	
Trifolium spp.	--		(17)	p	(25)	3
Vicia americana	(20)	p	(50)	p	--	
Viola adunca	(40)	1	--		--	
Zigadenus elegans	--		--		(50)	1
Z. venenosus	(20)	p	(33)	p	--	

[1]p = present with less than 0.5 percent canopy cover.

E10. — *Purshia tridentata* Series

Species constancy and average canopy cover for important plants in the following habitat types within the *Purshia tridentata* series: *Purshia tridentata/Agropyron spicatum* (MONT.) h.t. (*PUTR/AGSP*); *P. tridentata/Festuca scabrella* h.t. (*PUTR/FESC*); and *P. tridentata/Festuca idahoensis* h.t. (MONT.) (*PUTR/FEID*)

Species	*PUTR/AGSP* -- (1 stand)	*PUTR/AGSP* -- (4 stands)[2]	*PUTR/FESC* -- (4 stands)[1]	*PUTR/FEID* -- (1 stand)[2]
	- - - - - -	- - - - - -	Percent	- - - - - -
Medium Shrubs				
Chrysothamnus nauseosus	2	+	(25) p	
C. viscidiflorus	1	+	(25) p	
Purshia tridentata	p[3]	**	(100) 17	***
Rosa arkansana		+	(25) 1	+
Low Shrubs				
Artemisia frigida		*	(25) p	+
A. dracunculus	p			
Graminoids				
Agropyron spicatum	58	**	(100) 35	**
Aristida longiseta			(25) p	
Bromus mollis			(50) p	
B. tectorum	2	*	(75) 8	+
Festuca idahoensis			(100) 19	*
F. [illegible]			(75) 1	
F. scabrella			(100) 7	
Koeleria cristata	p	+	(100) 2	*
Poa sandbergii		+	(100) 5	*
Stipa comata		*	(25) 1	
S. occidentalis			(25) p	
S. viridula		+		*
Forbs				
Achillea millefolium	2	+	(100) 2	
Antennaria rosea		+	(50) p	+
Arabis holboellii	p		(25) p	
Arenaria congesta			(25) p	*
Arnica sororia			(50) p	
Arabidopsis thalina			(50) p	
[illegible] sagittata	12	*	(75) 10	
Centaurea maculosa		+		
Chaenactis douglasii	1			
Chrysopsis villosa	p	+	(25) 1	+
Collinsia parviflora			(100) 1	
Collomia limearis			(50) p	
Comandra umbellata			(50) p	
Crepis spp.		+	(75) p	
Epilobium minutum			(75) p	
Eriogonum corymbosus			(25) 3	
E. subtrinervis			(25) p	
[illegible]			(25) p	
E. umbellatum			(25) p	*

(con.)

APPENDIX E10 (con.)

Species	*PUTR/AGSP* -- (1 stand)	-- (4 stands)[2]	*PUTR/FESC* -- (4 stands)[1]	*PUTR/FEID* -- (1 stand)[2]
	- - - - - -	- - - - - - -	*Percent* - - - - -	- - - - - -
Forbs (con.)				
Hieracium albertinum			(50) 1	
Lepidium spp.			(50) 1	
Lithospermum ruderale		+	(75) p	
Lomatium triternatum			(75) p	
Lupinus serecius		+	(50) 1	*
Medicago spp.	1		(25) p	
Myosotis micrantha			(25) p	
Oxytropis spp.		+		+
Penstemon diphyllus	1			
Phacelia linearis	p		(75) p	
Phlox spp.	2		(25) p	
P. longifolia		+		+
P. hoodii				*
Physaria geyeri	1			
Stellaria spp.			(25) 2	
Taraxacum officinale			(50) p	
Tragopogon dubius	p	+	(100) 2	+

[1]Intensive plot data for average canopy cover in the *PUTR/AGSP* and *PUTR/FESC* habitat types and for species constancy (in parentheses) in the *PUTR/FESC* h.t.
[2]General reconnaissance data for average canopy cover in the *PUTR/AGSP* and *PUTR/FEID* habitat types (+ = <1%; * = 1-10%; ** = 10-20%; *** = >20%).
[3]p = present with less than 0.5 percent canopy cover.

E11. — *Cercocarpus ledifolius* Series

Species constancy and average canopy cover for important plants within the *Cercocarpus ledifolius/Agropyron spicatum* h.t. (*CELE/AGSP*)

Species	*CELE/AGSP* (1 stand)[1]	*CELE/AGSP* (2 stands)[2]
	- - - - - Percent	- - - - -
Medium and Tall Shrubs		
Artemisia arbuscula	p[3]	
A. tridentata		*
Cercocarpus ledifolius	19	**
Chrysothamnus nauseosus		+
Juniperus scopulorum	p	
Rhus trilobata		+
Low Shrubs		
Artemisia frigida	2	*
Eurotia lanata		+
Gutierrezia sarothrae	7	*
Opuntia polyacantha	p	
Graminoids		
Agropyron spicatum	9	**
Aristida longiseta	p	
Bouteloua gracilis	p	
Carex filifolia	1	
C. stenophylla	p	
Koeleria cristata	1	*
Oryzopsis hymenoides		*
Poa sandbergii	p	
Stipa comata	7	*
Forbs		
Allium cernuum	p	
Antennaria rosea		+
Comandra umbellata	p	
Draba oligosperma	p	
Erigeron caespitosa		*
Eriogonum microthecum		+
E. umbellatum	p	
Happlopappus acaulis		*
Lesquerella alpine	p	
Linum perenne	p	
Lithospermum ruderale		+
Mamillaria missouriensis	p	
Petrophytum caespitosum	p	
Phlox albomarginata	1	
P. hoodii		*

[1]Intensive plot data for species constancy average canopy cover in the *CELE/AGSP* h.t.

[2]General reconnaissance data for average canopy cover in the *CELE/AGSP* h.t. (+ = <1%; * = 1-10%; ** = 10-20%; *** = >20%).

[3]p = present with less than 0.5 percent canopy cover.

E12. — *Rhus trilobata* Series

Species constancy (in parentheses) and average canopy cover for important species in the *Rhus trilobata/Agropyron spicatum* h.t. (*RHTR/AGSP*), and in the *R. trilobata/Festuca idahoensis* h.t. (*RHTR/FEID*)

Species	*RHTR/AGSP* (4 stands)	*RHTR/FEID* (1 stand)
	- - - - - - *Percent* - - - - - -	
Medium Shrubs		
Amelanchier alnifolia	(25) p[1]	--
Artemisia tridentata	(25) p	--
Chrysothamnus nauseosus	(75) p	--
C. viscidiflorus	(25) p	--
Juniperus scopulorum	(25) p	--
Prunus virginiana	(50) 1	--
Rhus trilobata	(100) 23	14
Ribes cereum	(25) 1	--
Rosa arkansana	--	p
Low Shrubs		
Artemisia campestris	(25) p	p
A. dracunculus	(25) p	--
A. frigida	(75) 1	3
Juniperus horizontalis	--	p
Opuntia polyacantha	(100) p	--
Graminoids		
Agropyron smithii	(25) 1	--
A. spicatum	(100) 41	18
Aristida longiseta	--	1
Bouteloua gracilis	--	4
Bromus tectorum	(100) 4	p
Calamagrostis montanensis	--	p
Carex pennsylvanica	--	3
Festuca idahoensis	--	6
Koeleria cristata	(25) p	1
Muhlenbergia cuspidata	--	1
Oryzopsis hymenoides	(25) 5	--
Poa pratensis	--	3
P. sandbergii	(25) p	--
Stipa comata	--	4
S. viridula	(25) p	p
Forbs		
Achillea millefolium	(75) p	3
Allium cernuum	--	1
Antennaria parvifolia	--	1
Aster falcatus	(25) p	--
Astragalus drummondii	(25) p	--
Besseya wyomingensis	(25) p	1
Cerastium arvense	--	2
Chaenactis douglasii	(25) p	--
Chrysopsis villosa	(75) 1	9
Cirsium undulatum	(75) p	p

(con.)

APPENDIX E12 (con.)

Species	RHTR/AGSP (4 stands)		RHTR/FEID (1 stand)
	- - - - - *Percent* - - - - -		
Forbs (con.)			
Comandra umbellata	(25)	p	p
Erigeron caespitosus	--		p
[illegible]	(25)	p	--
[illegible]	(25)	p	--
Gaillardia aristata	--		1
Gaura coccinea	(50)	p	p
Geum triflorum	--		1
Haplopappus acaulis	(25)	p	--
H. nuttallii	(25)	p	--
Lepidium spp.	--		p
Liatris punctata	(25)	p	1
Linum perenne	(25)	p	p
Melilotus officinalis	(50)	1	--
Mentzelia dispersa	(50)	p	--
Petalostemon purpureum	(25)	p	1
Phlox albomarginata	(25)	p	--
P. hoodii	(25)	p	2
Plantago purshii	--		p
Potentilla arguta	--		p
P. hippeana	--		p
Psoralea tenuiflora	(50)	1	--
Ratibida columnifera	--		p
Senecio canus	(25)	p	--
Solidago missouriensis	--		p
Sphaeralcea coccinea	(75)	p	--
Taraxacum officinale	--		p
Thermopsis rhombifolia	--		p
Tragopogon dubius	(50)	1	p
Vicia americana	(75)	2	--

[1]p = present with less than 0.5 percent canopy cover.

E13. — *Sarcobatus vermiculatus* Series

Average canopy cover for important plants in the *Sarcobatus vermiculatus/Agropyron smithii* h.t. (*SAVE/AGSM*), and *S. vermiculatus/Elymus cinereus* h.t. (*SAVE/ELCI*)

Species	*SAVE/AGSM* (1 stand)[1]	*SAVE/AGSM* (2 stands)[2]	*SAVE/ELCI* (2 stands)[2]
	- - - - - - - -	percent	- - - - - - - -
Medium Shrubs			
Atriplex nuttallii	5	+	
Chrysothamnus viscidiflorus		+	*
Sarcobatus vermiculatus	3	**	**
Low Shrubs			
Artemisia frigida		+	+
Gutierrezia sarothrae			+
Opuntia polyacantha		*	*
Graminoids			
Agropyron smithii	55	**	**
A. spicatum			*
Bouteloua gracilis		**	
Bromus tectorum		+	
Carex filifolia			+
Elymus cinereus			*
Koeleria cristata			*
Poa juncifolia	2		
P. pratensis			+
Stipa comata		*	
S. viridula		+	
Forbs			
Aster chilensis			+
Chenopodium spp.		+	
Comandra umbellata			+
Iva axillaris			+
Tragopogon dubius		+	+
Sphaeralcea coccinea			+

[1]Intensive plot data for average canopy cover in the *SAVE/AGSM* h.t.

[2]General reconnaissance data for average canopy cover in the *SAVE/AGSM* and *SAVE/ELCI* habitat types (+ = <1%; * = 1-10%; ** = 10-20%; *** = >20%).

APPENDIX F

APPENDIX F —

PALATABILITY RATINGS

Palatability ratings for important plants in grassland and shrubland habitat types of western Montana have been compiled from published literature and guides for range managers[1]

Species	Palatability to: Cattle	Sheep	Deer	Elk
Medium Shrubs				
Artemisia arbuscula	P-F	F-G	F	G
A. tridentata	VP	P	P-G	P-F
A. tripartita	VP	VP	F	P-F
Cercocarpus ledifolius	F	F	G-E	G-E
Chrysothamnus nauseosus	VP	VP	VP	VP
C. viscidiflorus	F	F-G	F-G	F
Juniperus scopulorum	VP	P	P-F	P
Potentilla fruticosa	P	P-F	P-F	P-F
Prunus virginiana	P-F	P-F	G	G
Purshia tridentata	F-G	F-G	E	E
Rhus trilobata	VP	VP	F-G	P-F
Ribes cereum	P	P-F	F	F
Rosa arkansana	P-F	F	F-G	F-G
Sarcobatus vermiculatus	VP	PO	VP	VP
Tetradymia canescens	VP	PO	VP	VP
Low Shrubs				
Arctostaphylos uva-ursi	P	P	F	F
Artemisia frigida	P-F	F	F	F
Eurotia lanata	G	G	G	G
Gutierrezia sarothrae	VP	VP	VP	VP
Juniperus horizontalis	VP	P	P-F	P
Opuntia polyacantha	VP	VP	VP	VP
Vaccinium scoparium	P	P-F	P-F	F-G
Graminoids				
Agropyron caninum	G	G	G	G
A. dasystachyum	F-G	F-G	F-G	F-G
A. smithii	E	E	E	E
A. spicatum	E	E	E	E
Agrostis diegoensis	VG	VG	VG	VG
A. humilis	VG	VG	VG	VG
A. scabra	G	F	F	G
Alopecurus pratensis	F	F	F	F
Aristida longiseta	F	F	F	F
Bouteloua gracilis	VG	G	G	G
Bromus anomalus	E	E	E	E
B. carinatus	E	E	E	E
B. ciliatus	E	E	E	E
B. tectorum	F	F-G	F-G	F
Calamagrostis montanensis	F-G	P-F	P-F	F-G
C. purpurescens	F-G	F	F	F
C. rubescens	P-F	P	P	F
Carex albonigra	P-F	F-G	F-G	P-F
C. athrostachya	F-G	F	F	F-G
C. capillaris	F	F-G	F-G	F-G
C. [illegible]	F	G	F	F
C. hoodii	F-G	F	[illegible]	F-G
C. obtusata	F-G	F-G	F-G	F-G
C. pachystachya	G	G	G	G
C. pennsylvanica	F-G	F-G	F-G	F-G
C. petasata	G	G	G	G
C. platylepis	F	F-G	F-G	F-G
C. raynoldsii	F-G	[illegible]	F	F-G
C. [illegible]	F	F	[illegible]	[illegible]
C. stenophylla	[illegible]	F	F	F
C. vallicola	G	G	G	G
Danthonia intermedia	G	G	F	G
D. parryi	F	F	F	F
Deschampsia cespitosa	G	G	G	G
Elymus cinereus	P-F	P	F	P-F
Festuca idahoensis	G-VG	G-VG	G-VG	G-E
F. [illegible]	F-G	G	G	F-G
F. scabrella	VG	F	F	VG
Helictotrichon hookeri	F-G	F	F	G
Hesperochloa kingii	F-G	F	F	F-G
Juncus balticus	G	F-G	F	F
J. mertensianus	F	F	F	F
J. parryi	F	F-G	F-G	G
Koeleria cristata	G	G	G	G
Luzula parviflora	F-G	P-F	F	G
L. spicata	F	P-F	F	G
Melica bulbosa	G-E	G	F-G	G
M. spectabilis	G-E	G	F-G	G
Muhlenbergia cuspidata	F	F	F	F
M. richardsonii	G	F	F	F
Oryzopsis hymenoides	G-VG	G-VG	G-VG	G-VG
Phleum alpinum	G-VG	F-G	G-VG	G-VG
P. pratense	VG	G	F	VG
Poa cusickii	G	G	G	G
P. interior	F-G	F-G	F-G	F-G
P. juncifolia	G	G	F-G	G
P. pratensis	VG	VG	G	G
P. sandbergii	G	G	G	G
Sporobolus cryptandrus	G	F-G	[illegible]	F-G
Stipa comata	F-G	F	F	F-G
S. occidentalis	G	G	F	F-G
S. richardsonii	G	G	F	F-G
S. spartea	F	F	F	F
S. viridula	G	G	G	G
Trisetum spicatum	G	P-F	P-F	F-G
T. wolfii	F-G	F	F	F

(con.)

Species	Palatability To Cattle	Sheep	Deer	Elk	Species	Palatability To Cattle	Sheep	Deer	Elk
Forbs									
[illegible]	P-F	P-F	P-F	P-F	*Geum rossii*	VP	P-F	P-F	VP
[illegible]	F	G-VG	G	G	[illegible]	VP	VP	VP	VP
[illegible]	F	F-G	F-G	F-G	*Haplopappus acaulis*	VP	P	P	P
[illegible]	F	G	G	G	*Hedysarum* spp.	G	G	G	G
[illegible]	P	P-F	F	F	*Helianthella uniflora*	P-F	F-G	F-G	P-F
[illegible]	VP	P-F	P-F	P-F	*Heuchera* spp.	P	P	P	[illegible]
[illegible]	P	[illegible]	F	P	*Hieracium albertinum*	[illegible]	G	G	G
[illegible]	P	F	F	P	*Hymenoxys acaulis*	VP	VP	VP	VP
[illegible]	P	F	[illegible]	P	*Lepedium* spp.	P	P	P	P
A. ro[illegible]	P	F	F	P	*Liatris punctata*	P	P-F	P-F	[illegible]
[illegible]	P-F	F	F	P-F	[illegible]	P-F	[illegible]	[illegible]	F
Arnica chamissonis	VP	VP	VP	VP	*Lithospermum ruderale*	VP	P	P	P
[illegible]	[illegible]	P	P	P	*Lomatium triternatum*	P-F	F-G	G	G
A. sororia	VP	VP	VP	VP	[illegible]	P	PO	VP	VP
[illegible]	VP	P-F	P	P	[illegible]	P	PO	VP	VP
Aster campestris	P	P	P-F	P-F	*L. wyethia*	P-F	P-F	P-F	P-F
A. falcatus	P	P	P	P	*Melilotus officinalis*	G-VG	G-VG	G-VG	G-VG
[illegible]	P	F	F	F-G	*Monarda fistulosa*	P-F	[illegible]	[illegible]	F
[illegible]	P	P	F	F-G	*Oxytropis besseyi*	[illegible]	[illegible]	[illegible]	F
[illegible]		G	G	G	*O. sericea*	PO	PO	PO	PO
[illegible]	G	G	G	G	[illegible]	VP	VP	VP	VP
A. purshii	VP	VP	VP	VP	*Pedicularis contorta*	P	P-F	P-F	P-F
[illegible]	F	F	F	[illegible]	*Penstemon procerus*	P	F	F	F
[illegible]	F-G	F-G	VG	VG	[illegible]	VP	VP	VP	VP
[illegible]	P	F	F	P	*P. hoodii*	VP	VP	VP	VP
[illegible]	F	F-G	F-G	F	*P. kelseyi*	P	P-F	P-F	P
[illegible]	P-F	P-F	P-F	P-F	*P. longifolia*	P	P-F	P-F	P
Castilleja angustifolia	P	P-F	P-F	P-F	*P. multiflora*	P	P-F	P-F	P
[illegible]	VP	P	P	VP	*P. pulvinata*	VP	VP	VP	VP
[illegible]	P	P-F	F-G	P-F	*Plantago purshii*	P	P	P	[illegible]
[illegible]	P	P	P	P	*Polygonum bistortoides*	VP	P	P	P
Collinsia parviflora	VP	VP	VP	VP	*P. douglasii*	VP	P-F	P	P
Collomia linearis	VP	VP	VP	VP	*Potentilla arguta*	P-F	F-G	F-G	F
Comandra umbellata	P	F	F	P-F	*P. diversifolia*	VP	F	F	F
Crepis occidentalis	F	G	G	G	*P. glandulosa*	P	P-F	P-F	P-F
Cymopterus bipinnata	P	P-F	P-F	P-F	*P. gracilis*	VP	P	P	P
Delphinium bicolor	PO	F-G	F	[illegible]	[illegible]	VP	P	P	VP
D. occidentale	PO	F-G	F	F	*Rumex salicifolius*	P-F	[illegible]	[illegible]	F
[illegible]	P	P	P	P	*Sedum lanceolatum*	VP	VP	VP	VP
[illegible]	P	P	P	P	*Senecio cana*	P-F	F	F	P-F
[illegible]	P	P-F	F	F	[illegible]	P	F	F	F
[illegible]	P	P-F	[illegible]	F	*Solidago missouriensis*	P	P-F	P-F	P
[illegible]	P	P	P	P	*Sphaeralcea coccinea*	P	P	P	P
[illegible]	P	P-F	F	F	*Stellaria* spp.	F	F-G	F-G	F-G
[illegible]	P	P-F	F	F	*Taraxacum officinale*	F-G	G	G	G
[illegible]	[illegible]	P-F	F	F	*Thermopsis rhombifolia*	P	P	P	P
[illegible]*llatum*	P	P-G	F	F	*Tragopogon dubius*	P	F	F	F
[illegible]	F	F-G	F-G	F-G	*Veronica wormskjoldi*	P	P-F	P-F	P
[illegible]	P-F	F	F	P-F	*Vicia americana*	G-E	G-E	G-E	G-E
[illegible]	P	F	F	P	[illegible]	F	F	[illegible]	[illegible]
[illegible]	[illegible]	P-F	P-F	P-F	*Zigadenus elegans*	P	PO	P	P
[illegible]	F-G	G	G	F	*Z. venenosus*	P	PO	P	P

[1] E = excellent; VG = very good; G = good; F = fair; P = poor; VP = very poor; PO = poisonous.

APPENDIX G —

COMPARISONS OF DIFFERENTIALLY- GRAZED PAIRED STANDS

G1. — *Stipa comata* Series

Canopy cover and confidence levels of differentially grazed paired stands in the *Stipa comata* series[1]

Type of cover	*STCO/BOGR*		*STCO/BOGR AGSM* phase	
	Stand 102	Stand 103	Stand 167	Stand 168
	Grazing			
	(none)	(heavy)	(slight)	(moderate)
	Percent			
Cover class				
Shrubs	3.8	5.2	8.3 *[2]	13.4
Graminoids	61.3	57.8	72.6 **	60.2
Forbs	0.2	0.2	11.1	8.6
Bryophytes	10.8 *	6.8	14.1 +	16.1
Bare ground	19.2	23.1	5.0 **	16.1
Litter	2.7	3.4	69.8 **	48.2
Rock	7.1	5.1	13.7 **	1.1
Shrubs				
Artemisia frigida	p[3]		7.6 +	10.1
Chrysothamnus nauseosus				1.9
Gutierrezia sarothrae	p	0.8	0.8	0.7
Eurotia lanata	p	p		0.4
Opuntia polyacantha	3.8	4.4		0.8
Graminoids				
Agropyron smithii			3.5 +	1.6
A. spicatum			0.4	0.1
Bouteloua gracilis	53.9	54.7	8.9 **	22.6
Calamagrostis montanensis			4.3 **	9.7
Carex filifolia			20.0 **	9.0
C. stenophylla	10.3	9.2	1.0 **	4.0
Koeleria cristata			6.6 **	0.6
Poa sandbergii			p +	0.8
Sitanion hysterix	0.4			
Stipa comata	9.6 *	3.3	29.3 **	7.6
Forbs				
Astragalus ceramicus			0.4	p
A. drummondii			1.7	1.4
A. purshii	0.1	0.1	0.1	
Hymenoxys acaulis			0.6	
Liatris punctata			0.1	
Lygodesmia juncea			0.5	
Melilotus officinalis			0.1 *	0.5
Paronychia sessiliflora			5.8	3.8
Phlox hoodii			2.5 +	0.8
Sphaeralcea coccinea	p	0.2	p **	2.2
Thelesperma marginatum			0.6	0.1

[1]See the narrative in appendix G6 for the location and history of these stands.
[2]Confidence levels (** = >99%; * = 95-98%; + = 90-94% probability of differing statistically).
[3]p = present with less than 0.5 percent canopy cover.

G2. — *Agropyron spicatum* Series

Canopy cover and confidence levels of differentially grazed paired stands in the *Agropyron spicatum* series[1]

Type of cover	*AGSP/BOGR*		*AGSP/BOGR*		*AGSP/BOGR*		[illegible]	
	Stand 107	Stand 108	Stand 16	Stand 17	Stand 13	Stand 12	Stand 194	Stand 195
	Grazing							
	(none)	(moderate)	(none)	(heavy)	(moderate)	(heavy)	(none)	(moderate)
	[illegible]							
Cover class								
Shrubs	3.5**[2]	14.6	1.8	1.6	P	0.4	23.1**	10.0
Graminoids	44.6 *	36.5	40.7	39.6	68.0**	45.7	76.2**	56.0
Forbs	P	0.7	12.8	10.6	19.1	15.3	28.4**	65.7
Bryophytes	25.6	24.9	4.5		21.6	17.7	11.7 *	1.4
Bare ground	18.3	16.2	30.0	*42.1	1.6**	5.8	1.4**	6.3
Litter	21.8	+16.3	17.4	*11.6	22.1	+27.5	76.4**	63.7
Rock	6.8**	17.9	1.6	1.8	3.2	4.5	8.9**	14.7
Shrubs								
Artemisia frigida	2.5	4.5	8.2	6.8	0.9 *	3.2	15.6**	3.4
Artemisia tridentata			P	0.9				
[illegible]			P	0.1		0.4		
[illegible]			0.8	0.1				
[illegible]	P**	4.4	1.2	2.0	P	0.9	10.5**	1.4
[illegible]								3.2
[illegible]				0.4				
Opuntia polyacantha			1.0	0.1				
Potentilla fruticosa							P	2.1
Rosa arkansana		0.4						0.1
Graminoids								
Agropyron dasystachyum							22.0**	10.4
[illegible]	25.9**	6.1	16.2**	3.4	14.6**	1.7	3.3 +	0.8
Bouteloua gracilis	10.9	13.8	9.5**	22.8	10.7**	4.5		
[illegible]						2.6		
Calamagrostis montanensis					0.1 +	1.1	2.3 *	0.5
[illegible]							4.6	5.4
C. stenophylla	3.9 *	6.7	1.7 *	3.8	0.7	1.2	1.4	2.5
Helictotrichon hookeri								**13.7
Koeleria cristata			0.1	0.4	15.7**	0.8	8.1	10.2
Muhlenbergia cuspidata								0.4
Poa cusickii							6.6	7.5
P. pratensis						1.9		
P. sandbergii	3.0	4.3	2.3 *	5.1	2.6	2.9		
Stipa comata	7.2	*12.7	13.8	9.8	18.2**	30.2	9.9**	0.2
[illegible]							25.7**	

(con.)

Type of cover	AGSP/BOGR		AGSP/BOGR		AGSP/BOGR		AGSP/AGSM	
	Stand 107	Stand 108	Stand 16	Stand 17	Stand 13	Stand 12	Stand 194	Stand 195
	Grazing							
	(none)	(moderate)	(none)	(heavy)	(moderate)	(heavy)	(none)	(moderate)
	Percent							
Forbs								
Achillea millefolium							0.4	0.1
Antennaria rosea					0.2	P		
Astragalus purshii							0.2	0.1
Aster falcatus							3.4	1.9
Cerastium arvense							2.5	1.6
Chrysopsis villosa			0.4		0.2 *	2.2	0.1	P
Clematis hirsutissima							P	0.2
Comandra umbellata							2.3	2.4
Cryptantha celosioides							0.1	0.2
Cynoglossum officinale							0.9	
Erigeron caespitosus					0.2	0.2	0.7	1.0
E. divergens			0.2	0.2				
E. filifolius			P				0.1**	2.5
Eriogonum umbellatum							P	0.6
Eritrichum howardii							*	1.8
Galium boreale							1.2**	6.3
Grindelia nana			0.1					
G. squarrosa						0.6	P	
Hymenoxys acaulis							3.9**	9.0
Hymenopappus filifolius								2.3
Lesquerella alpina							1.6**	5.8
Lithospermum incisum					0.1	0.4		
Liatris punctata					4.5**	0.1	0.1	P
Lygodesmia juncea			1.0 *					
Linum perenne							1.3	1.1
Oxytropis riparia					15.0**	5.2		
Paronychia sessiliflora							3.9 *	7.4
Phlox alyssifolia							2.1 +	4.2
P. hoodii	P	0.2	1.0	0.8	1.8**	0.2	7.4 *	12.8
Plantago purshii	**	0.2			**	0.2		
Potentilla pennsylvanica					**	0.5	0.1	0.2
Senecio canus								1.2
Sphaeralcea coccinea	P **	0.1	0.9	0.9	P	0.6		
Taraxacum officinale					P **	1.6	1.0 *	
Tragopogon dubius					*	0.4	1.2 +	

[1]See the narrative in appendix G6 for the location and history of these stands.
[2]Confidence levels (** = >99%; * = 95-98%; + = 90-94% probability of differing statistically).

G3. — *Festuca scabrella*/*Agropyron spicatum* h.t.

[illegible] cover and confidence levels of differentially grazed paired stands in the [illegible] *Festuca scabrella* [illegible]

Type of cover	Stand 252	Stand 253	Stand 87	Stand 88	Stand 366	Stand 367	Stand [illegible]	Stand [illegible]	Stand [illegible]	Stand [illegible]
	Grazing									
	slight	moderate	slight	moderate	slight	heavy	[illegible]	moderate	slight	[illegible]
Cover class										
Shrubs	1.1**	8.7	2.1 +	[illegible]	0.5	7.1	4.7	[illegible]	[illegible]	0.4
Graminoids	91.[illegible]**	66.2	55.7**	30.1	68.1**	49.4	70.5**	52.8	81.7**	64.[illegible]
Forbs	11.8	14.6	15.5**	58.4	26.0	25.0	15.0	16.2	12.7**	40.4
Bryophytes	18.8**	11.0	10.3**	2.6	16.8**	3.3	0.5	1.8	16.2	16.3
Bare ground	1.0**	10.1	8.0	9.7	2.0**	8.0	1.5**	13.4		
Litter	85.9**	71.9	40.4 *	17.6	75.4**	43.8	84.6**	43.5	88.5	88.4
Rock	0.5**	5.8	1.0	1.8	5.8**	15.4	P	+ 0.7		
Shrubs										
Artemisia cana			2.0 *		0.4	0.1			0.4	
A. [illegible]							0.9	[illegible].1		
A. frigida	1.1 **	3.4	0.4	1.4	8.7	7.1	3.8	1.6	0.1	0.5
Chrysothamnus nauseosus			P	* 1.7						
C. viscidiflorus			P	0.1						
Gutierrezia sarothrae		** 4.6	P	0.1		0.2			P	0.1
Rosa [illegible]					0.2	0.1				
Tetradymia canescens			0.1	2.4					0.5	P
Graminoids										
Agropyron smithii	3.6**				3.4**	2.0				
A. spicatum	2.6	4.9	4.2	4.3	11.0**	1.8	11.1	15.7		* 1.2
Bouteloua gracilis	0.6 +	2.2			1.1**	5.4	0.1 *	5.7		
Calamagrostis montanensis					0.4	0.2				
Carex filifolia					1.4	3.6				
C. [illegible]									2.4**	11.6
C. [illegible]										0.8
C. stenophylla	2.6	1.7	2.1 *	0.2	1.3	0.8		** 3.8		
Danthonia unispicata				0.2						
Festuca idahoensis	36.9**	8.2	21.4**	32.1			11.9**	4.1		
F. scabrella	73.9**	33.6	27.0**	1.4	21.3**	4.7	18.8**	7.0	81.1**	32.4
Koeleria cristata	0.5**	8.8	4.1	4.4	5.6**	15.2	0.4**	6.4	0.2 *	1.5
Muhlenbergia cuspidata					3.1 +	5.8				
Poa [illegible]			0.5	0.1	0.2		P	0.4	0.5 +	0.2
P. [illegible]		3.8	0.5	0.4						
Stipa comata					4.1	2.5	0.8	1.2		
S. [illegible]									1.0**	3.4

(con.)

Type of cover	Stand 232	Stand 233	Stand 87	Stand 88	Stand 366	Stand 367	Stand 330	Stand 331	Stand 33[illegible]	Stand 33[illegible]
	Grazing									
	(slight)	(moderate)	(slight)	(moderate)	(slight)	(heavy)	(none)	(moderate)	(slight)	(heavy)
Forbs										
Achillea millefolium	1.4 *	p	p	0.6			1.5		1.0	1.8
Agoseris glauca					0.5		p **	0.5		
Allium cernuum	0.2			0.2			1.0	[illegible]		
Antennaria parvifolia		2.4				0.2				
A. rosea	1.7 *	0.4	0.6	1.0			1.8	1.8	p	1.4
Arabis holboellii				0.4						
A. lignifera	0.2	0.5								
Arenaria congesta	1.1 **	0.7	0.1	0.4						
Arnica fulgens	1.0	0.5								
A. sororia							1.4	1.4		
Artemisia ludoviciana	0.4	p					p	0.1	6.[illegible] **	15.[illegible]
Aster falcatus			0.4	p	1.4	0.8			1.5 +	3.1
Astragalus drummondii				1.6			1.0	0.1		
Balsamorhiza incana	1.5 *	p								
Besseya wyomingensis		0.6								
Cerastium arvense					1.6 +	0.5	0.1		0.2	0.9
Chrysopsis villosa	2.8 *	0.8	1.1	2.3	0.4	0.1	p	0.1	0.6 +	2.1
Cirsium vulgare			p +	1.0						
Comandra umbellata					0.8	1.0		0.2		+ 1.0
Crepis acuminata							0.1	0.7		
Erigeron caespitosus					0.2	0.1				
E. compositus									0.8	0.2
E. corymbosus			p	0.4						
E. filifolius						0.[illegible]				
Eriogonum ovalifolium										
Gaillardia aristata					0.6	0.2				
Gaura coccinea	0.8	p	p **	1.8	0.1		0.1	0.1		
Geum triflorum	p	0.4							[illegible].2 **	1.[illegible]
Hymenoxys acaulis					2.0	3.2				
Liatris punctata					8.4 **	2.8	p	0.2	[illegible]	[illegible]
Lithospermum ruderale	0.1	0.1	0.4	0.1			0.4	0.1		
Lomatium spp.							0.6	1.5		
Lupinus sericeus			8.8 **	28.8			7.7 +	3.0	0.1	
Lygodesmia juncea					0.1					
Oxytropis lambertii	1.9 *		1.9 *							
O. sericea					0.8	1.5				
Paronychia sessiliflora					1.5	1.6				
Petalostemon purpureum					0.2	0.4				
Phlox alyssifolia					1.4 *	0.6				
P. longifolia			1.0	1.1						
P. hoodii					1.1 **	8.5	0.1	1.5	[illegible]	[illegible]
Potentilla pensylvanica	p	0.1								
Senecio canus					0.1	0.2				
Solidago missouriensis	+	0.2	0.3 **	2.0	1.6	0.6			0.1	
Sphaeralcea coccinea	**	0.8	0.1	0.2						
Taraxacum officinale	0.5 *		0.1	0.2						
Thelesperma marginatum				1.9	0.5 **					
Tragopogon dubius			0.1 *		0.2		0.1	0.[illegible]		
Vicia americana	0.1	0.2			p				0.1 **	[illegible]
Zigadenus venenosus							[illegible]	0.1		

[1]See the narrative in appendix G6 for the location and history of these stands.
[2]Confidence levels (** = >99%; * = 95-98%; + = 90-94% probability of differing statistically).
[3]p - present with less than 0.5 percent canopy cover.

G3. — *Festuca scabrella*/*Agropyron spicatum* h.t.

[illegible] cover and confidence levels of differentially grazed paired stands in the [illegible] series[illegible]

Type of cover	Stand 252	Stand 253	Stand 57	Stand 58	Stand 300	Stand 301	Stand [illegible]	Stand [illegible]	Stand [illegible]	Stand [illegible]
	Grazing									
	(slight)	(moderate)	(slight)	(moderate)	(slight)	(heavy)	[illegible]	[illegible]	[illegible]	[illegible]
Cover class										
Shrubs	1.1**	8.7	2.4 +	6.2	0.5	7.9	4.7	2.3	1.1	6.1
Graminoids	91.0**	66.2	55.7**	39.1	68.4**	49.4	70.5**	51.8	81.7**	64.7
Forbs	11.8	14.6	15.5**	38.1	26.0	25.0	13.0	16.7	12.5**	18.4
Bryophytes	18.8**	11.0	10.3**	2.6	16.8**	0.5	0.3	1.5	16.2	16.4
Bare ground	1.0**	10.4	8.0	9.7	2.0**	8.0	1.5**	13.4		
Litter	85.9**	71.9	40.4 *	17.6	73.4**	43.8	84.0**	45.3	88.5	88.1
Rock	0.5**	3.8	1.0	1.8	3.8**	15.1	p +	0.7		
Shrubs										
Artemisia cana			2.0 *		0.1	0.1			0.4	
A. tridentata							0.3	0.1		
A. frigida	1.1 **	3.4	0.4	1.4	8.7	7.1	3.8	1.6	2.1	0.5
Chrysothamnus nauseosus			p *	1.7						
C. viscidiflorus			p	0.1						
Gutierrezia sarothrae		** 4.6	p	0.1		0.2			p	0.1
Rosa arkansana					0.2	0.1				
Symphoricarpos occidentalis			0.1	2.4					0.5	p
Graminoids										
Agropyron smithii	3.6**				5.4**	2.0				
A. spicatum	2.6	4.9	4.2	4.3	14.0**	1.8	11.1	15.7		* 1.2
Bouteloua gracilis	0.6 +	2.2			1.1**	5.4	0.1 *	5.7		
Calamagrostis montanensis					0.4	0.2				
Carex filifolia					4.4	3.6				
C. pensylvanica									2.4**	14.6
C. obtusata										0.8
C. stenophylla	2.0	1.7	2.1 *	0.2	1.3	0.8		** 3.8		
Danthonia unispicata				0.2						
Festuca idahoensis	36.9**	8.2	21.4**	32.1			11.9**	4.1		
F. scabrella	73.9**	33.6	27.0**	1.4	21.3**	4.7	48.8**	7.0	81.1**	32.4
Koeleria cristata	0.5**	8.8	4.1	4.4	5.6**	15.2	0.4**	6.4	0.2 *	1.5
Muhlenbergia cuspidata					3.1 +	5.8				
Poa [illegible]			0.5	0.1	0.2		p	0.4	0.5 +	0.2
P. sandbergii		3.8	0.5	0.4						
Stipa comata					4.1	2.3	0.8	1.2		
S. [illegible]									1.0**	3.4

(con.)

Type of cover	Stand 252	Stand 233	Stand 87	Stand 88	Stand 366	Stand 367	Stand 350	Stand 351	Stand 35[illegible]	Stand 35[illegible]
	Grazing									
	(slight)	(moderate)	(slight)	(moderate)	(slight)	(heavy)	(none)	(moderate)	(slight)	(heavy)
	Percent[2]									
Forbs										
Achillea millefolium	1.4 *	p	p	0.6			1.5		1.6	1.8
Agoseris glauca					0.5		p **	0.5		
Allium cernuum	0.2			0.2			1.0	0.2		
Antennaria parvifolia		2.4				0.2				
A. rosea	1.7 *	0.4	0.6	1.0			1.8	1.8	p	1.4
Arabis holboellii				0.4						
A. [illegible]	0.2	0.5								
Arenaria congesta	1.1 **	6.7	0.1	0.4						
Arnica fulgens	1.0	0.3								
A. sororia							1.4	1.4		
Artemisia ludoviciana	0.4	p					p	0.1	6.0 **	13.6
Aster falcatus			0.4	p	1.4	0.8			1.3 +	7.4
Astragalus drummondii				1.6			1.0	0.1		
Balsamorhiza incana	1.5 *	p								
Besseya wyomingensis		0.6								
Cerastium arvense					1.6 +	0.5	0.1		0.2	0.3
Chrysopsis villosa	2.8 *	0.8	1.1	2.5	0.4	0.1	p	0.1	0.6 +	2.1
Cirsium vulgare			p +	1.0						
Comandra umbellata					0.8	1.0		0.2	+	1.0
Crepis acuminata							0.1	0.7		
Erigeron caespitosus					0.2	0.1				
E. corymbosus									1.8	0.[illegible]
E. compositus			p	0.4						
E. filifolius						0.2				
Eriogonum umbellatum										
Gaillardia aristata					0.6	0.2				
Galium boreale	0.8	p	p **	1.8	0.1		0.1	0.1		
Geum triflorum	p	0.4							0.2 **	1.[illegible]
Hymenoxys acaulis					2.0	5.2				
Liatris punctata					8.4 **	2.8	p	0.2	1.2	0.6
Lithospermum ruderale	0.1	0.1	0.4	0.1			0.4	0.1		
Lomatium spp.							0.6	1.5		
Lupinus sericeus			8.8 **	28.8			7.7 +	3.0	0.1	
Lygodesmia juncea					0.1					
Oxytropis lambertii	1.9 *		1.9 +							
O. sericea					0.8	1.5				
Paronychia sessiliflora					0.5	1.6				
Petalostemon purpureum					0.2	0.4				
Phlox albomarginata					1.4 *	0.6				
P. longifolia			1.0	1.1						
P. hoodii					1.4 **	8.5	0.1	1.3	[illegible]	[illegible]
Potentilla pensylvanica	p	0.1								
Senecio canus					0.1	0.2				
Solidago missouriensis	+	0.2	6.5 **	2.0	1.6	0.6			0.1	[illegible]
Sphaeralcea coccinea	**	0.8	0.1	0.2						
Taraxacum officinale	0.5 *		0.1	0.2						
Thelesperma marginatum				1.9	0.5 **					
Tragopogon dubius			0.1 *		0.2		0.1	0.2		
Vicia americana	0.1	0.2			p				[illegible]	[illegible]
Zigadenus venenosus							0.2	0.1		

[1]See the narrative in appendix G6 for the location and history of these stands.
[2]Confidence levels (** = 99%; * = 95-98%; + = 90-94% probability of differing statistically).
[3]p = present with less than 0.5 percent canopy cover.

G4. — *Festuca scabrella/Festuca idahoensis* h.t.

Canopy cover and confidence levels of differentially grazed paired stands in the *Festuca scabrella/Festuca idahoensis* h.t. and the *Geranium viscosissimum* phase of the *Festuca scabrella* series[1]

Type of cover	FESC/FEID			FESC/FEID GEVI phase			FESC/FEID GEVI phase		
	Stand 198		Stand 199	Stand 37		Stand 38	Stand 241		Stand 242
	Grazing								
	(none)		(heavy)	(none)		(moderate)	(none)		(heavy)
	Percent								
Cover class									
Shrubs	p[3]		0.9				0.1		0.1
Graminoids	82.5	**[2]	75.4	60.9		67.4	71.5	**	38.4
Forbs	17.5	**	19.9	48.4		54.4	68.4	**	49.9
Bryophytes	44.5	**	9.7	0.4		0.3	63.4	**	90.4
Bare ground	p	*	0.4	3.7		2.7	0.4		0.3
Litter	83.8		84.4	29.3		29.6	81.1	**	59.6
Rock				4.6	+	2.3	1.4	*	0.3
Shrubs									
Artemisia tridentata	p		0.9						
Graminoids									
Agropyron dasystachyum	0.1		0.8						
A. spicatum				p		0.8	18.4	**	2.2
Carex obtusata				2.7	**	8.1			
C. petasata				1.0	**	3.4	2.0		0.6
C. vallicola	21.0	**	0.2						
Danthonia intermedia						0.6	p		1.7
D. unispicata	0.2	**	40.8			0.1			
Festuca idahoensis	7.6	**	20.5	10.1	*	17.4	17.9		17.1
F. scabrella	71.1	**	4.3	44.6		35.3	41.7	**	4.2
Koeleria cristata			1.8	1.6		2.0	11.8	*	8.3
[illegible]	11.0								
P. pratensis							0.4		1.3
P. sandbergii				0.4		1.2		**	6.6
Stipa occidentalis						0.8			
Forbs									
Achillea millefolium	2.1		4.1	0.7	*	2.8	5.0	*	1.4
Agoseris glauca				2.1		2.1			
Allium cernuum				0.3		0.2	p	*	1.0
Anaphalis margaritacea						0.2			
Anemone patens				2.1		3.0			
Antennaria rosea	0.2	+	1.3	p		0.2	2.0		4.5
[illegible]							8.4	*	3.2
Arenaria congesta	0.3	*	1.8	1.6		2.1	1.4		2.3
Arabis hirsuta				0.2		0.5			
Arnica fulgens				2.4	**	8.7			
Artemisia ludoviciana	1.0	+	3.1						
Aster spp.	4.8								
A. falcatus		**	2.0						

(con.)

Type of cover	*FESC/FEID* Stand 198		*FESC/FEID* Stand 199	*FESC/FEID GEVI* phase Stand 37		*FESC/FEID GEVI* phase Stand 38	*FESC/FEID GEVI* phase Stand 241		*FESC/FEID GEVI* phase Stand 242
Grazing	(None)		(Heavy)	(None)		(Moderate)	(None)		(Heavy)
	Percent								
Forbs (con.)									
A. integrifolius	9.0	*	4.2						
A. campestris							2.6		1.8
Campanula rotundifolia				1.4		0.8	1.3		1.8
Cerastium arvense	0.2		0.4	1.6	*	5.4			
Centaurea maculosa								+	5.4
Clematis hirsutissima				3.2		4.4			
Dodecatheon conjugens							0.7	*	0.2
Draba crassifolia							0.5		0.3
Erigeron compositus							p	+	0.2
E. speciosus							5.1		5.1
E. subtrinervis				6.8	+	3.8			
Eriogonum umbellatum				6.0		5.8	5.0	+	1.6
Gaillardia aristata				0.4		0.4			
Geum triflorum	p		0.4		*	3.2	5.3	**	0.4
Geranium viscosissimum				6.4		7.9	29.2	**	10.5
Hieracium albertinum							3.9	*	p
H. cynoglossoides				8.4	**	0.4			
Heuchera cylindrica							3.1	*	p
Lomatium triternatum				0.1		0.1			
Lupinus sereceus				13.3		11.5			
Phlox longifolia							3.8	+	1.8
Potentilla arguta							2.0	**	
P. glandulosa				0.1		0.1			
P. gracilis				0.2		1.2	13.4	**	7.8
P. pennsylvanica	0.1	*	1.7						
Solidago missouriensis							1.0	+	0.1
S. occidentalis				2.3		2.4			
Taraxacum officinale					+	0.2		**	2.4
Tragopogon dubius									0.5
Vicia americana							0.1	+	0.9

[1]See the narrative in appendix G6 for the location and history of these stands.

[2]Confidence levels (** = >99%; * = 95-98%; + = 90-94% probability of differing stastistically).

[3]p = present with less than 0.5 percent canopy cover.

G5. — *Festuca idahoensis* Series

[illegible] cover and confidence levels of differentially grazed paired stands [illegible]

Type of cover	Stand 163 (none)	Stand 164 (moderate)	Stand 105 (none)	Stand 106 (moderate)	Stand 113 (none)	Stand 11[illegible] (moderate)	Stand [illegible] (none)	Stand [illegible] (moderate)	Stand [illegible] (light)	Stand [illegible] (moderate)	Stand [illegible]	Stand [illegible]
Cover class												
Shrubs	1.6 **	5.2	4.2 +	8.6	11.9 **	3.6			[illegible]	[illegible]		
Graminoids	67.1 **	49.4	71.9 *	64.1	85.4 **	66.8	78.2 **	[illegible]	[illegible] **	[illegible]	[illegible]	[illegible]
Forbs	34.9 **	8.9	33.1 **	13.9	31.0	25.7	62.1	65.4	72.1 **	[illegible]	[illegible]	[illegible]
Bryophytes	25.5	28.2	13.4 **	5.5	15.9 *	24.3	3.2 **	12.7	6.2 **	15.7	[illegible]	[illegible]
Bare ground	P **	6.5	0.9 **	6.5	0.2 **	3.7	0.6 **	1.6	[illegible] *	1.9	10.6 +	[illegible]
Litter	75.8 **	43.1	22.5	22.8	11.8 **	23.6	84.4 **	73.5	84.7 *	80.4	[illegible]	[illegible]
Rock	P **	5.0	0.7	0.2	0.6 +	2.0	1.9 **	10.3	1.1	1.2	[illegible]	[illegible]
Shrubs												
Artemisia nana	0.8	0.4			0.4							
A. dracunculus			P *	1.4								
A. frigida	0.8 **	3.8	0.4 *	3.7	0.6 *	2.5			5.5	1.1		
Chrysothamnus nauseosus	P	0.4	0.4	1.8	0.1							
C. viscidiflorus			3.2	2.1	7.7 **	1.2						
Tetradymia canescens	P	0.4	P		6.7 *	P						
Graminoids												
Agropyron caninum							3.2 +	0.5			0.4	0.1
A. dasystachyum							*	1.6				
A. smithii	4.0	3.8										
A. spicatum	P +	0.2	33.9 **	11.4	22.1 **	0.5	11.2 **	3.6	21.6 **	8.7		
Carex filifolia							1.6	1.7				
C. obtusata							17.8	15.7	26.1 **	16.9		
C. petasata									P	2.1	6.3	5.2
C. stenophylla	**	2.8	1.1 +	2.6	1.1 +	0.1					2.3	2.3
Danthonia intermedia							0.4				29.7 **	42.6
Festuca idahoensis	66.4 **	8.4	24.3	30.9	76.0 **	45.9	56.0 **	25.2	39.7	33.6	41.9 **	23.6
Helictotrichon hookeri							0.1 *	1.5	0.2 +	0.9		
Koeleria cristata	1.0	1.6	6.0	4.6	1.6	1.5	1.5	1.7	5.7	7.0	4.8 +	2.1
Poa cusickii	0.3 **	19.6					2.9	3.8	0.7	0.8		
P. scabrella											0.4	1.4
P. sandbergii	1.2 **	15.6	14.5 *	20.4	0.2 *	0.7						
Stipa comata			1.5 **	6.6	0.9 **	27.0			0.1	0.8		
S. occidentalis							1.6 *	0.2	2.4	3.6	6.0	7.0
Forbs												
Achillea millefolium			1.6 *	0.2	1.2	1.1	3.2	3.6	1.6 *	5.2	2.6	2.1
Agoseris glauca			11.4 **	1.7			7.0 **	1.5	3.2 *	P	4.7	5.4
Allium cernuum					0.1	0.1	0.9	0.6	P +	1.1		
Antennaria rosea	3.6	1.4	2.7 +	0.9	6.2 *	2.4	0.8	0.4	5.8	2.5	0.6	0.6
Arenaria congesta			0.7 +		2.0 *	0.1	3.2	4.5	1.4	2.6	0.2	0.2
Arnica fulgens	P +	0.9			P	0.1						
Artemisia ludoviciana	16.1 **	1.1	*	3.0					3.9 *			
[illegible]							8.7 **	2.6			4.5 **	

APPENDIX [illegible] (con.)

Type of cover	FEID/[illegible] Stand 163 (none)	FEID/[illegible] Stand 164 (moderate)	FEID/[illegible] Stand 105 (none)	FEID/[illegible] Stand 106 (moderate)	FEID/[illegible] Stand 113 (none)	FEID/[illegible] Stand 112 (moderate)	FEID/[illegible] [illegible] phase Stand 200 (none)	FEID/[illegible] [illegible] phase Stand 201 (moderate)	FEID/[illegible] [illegible] phase Stand 176 (slight)	FEID/[illegible] [illegible] phase Stand 177 (moderate)	FEID/[illegible] Stand 44 (none)	FEID/[illegible] Stand 43 (moderate)
	Grazing											
	Percent											
Forbs (con.)												
[illegible] spp.	5.4 **	1.1	0.4	P					2.0	1.8		
[illegible]					9.4 *	4.6						
[illegible]							0.4	0.1				
[illegible]							1.1	0.4	*	0.3		
[illegible]							0.4	0.4				
[illegible]									0.7 +	P		
[illegible]							2.1	1.2	0.4	0.6	0.5	0.2
[illegible]							8.2	8.5	3.8 **	0.6		
[illegible]			6.4 **	1.5								
[illegible]											0.1 **	8.6
[illegible]							3.8	1.9	3.5 *	7.4		
[illegible]											2.5 *	
[illegible]					0.4	0.2			0.1			
[illegible]	4.1 *	P	4.1	2.6	4.8	6.0	2.4 *	0.4	3.7	2.5		
[illegible]			1.3	0.8		0.1						
[illegible]							**	1.7	0.3 *			
[illegible]											5.2	4.4
[illegible]											1.6	0.8
[illegible]									0.4			
[illegible]											2.2	1.0
[illegible]							0.4	0.2				
[illegible]	1.8	0.8					8.4	10.2	3.8 **	1.0		
[illegible]							2.6	4.4	3.0 +	1.1		
[illegible]					**	0.6			0.9			
[illegible]											0.4	0.8
[illegible]									P	0.4	9.0 +	15.8
[illegible]	1.5											
[illegible]							0.4					
[illegible]							0.4	P				
[illegible]			1.6	P								
[illegible]					*	0.4						
[illegible]											[illegible] **	
[illegible]											0.3 +	1.2
[illegible]			0.4 **	2.6	12.5	15.0	2.1 +	P	6.9	8.5		
[illegible]	2.8 *	0.1										
[illegible]							P **	9.5				
[illegible]											1.8	3.4
[illegible]	2.0	1.6	0.8 +	2.9	0.4		5.9 **	12.8	10.4	10.6		
[illegible]											2.7 *	[illegible]
[illegible]							0.2					
[illegible]											0.9	
[illegible]											[illegible]	[illegible]
[illegible]											[illegible]	0.2
[illegible]			0.2				0.1	0.2	P	[illegible]		
[illegible]							0.1 **	0.6	0.2			
[illegible]							P				**	[illegible]
[illegible]	0.1		0.1	P	0.2	0.1	0.2		0.2 **	[illegible]	*	[illegible]
[illegible]			0.6	P	1.1 **	0.1			1.1 *			
[illegible]							[illegible] **	1.1				
[illegible] spp.					[illegible]		[illegible] +	P	0.1			

[1]See the narrative in Appendix G-6 for the location and history of these stands.
[2]Confidence levels (** = .99, * = .95-.98, + = .90-.94) probability of differing statistically.
[3]P = present with less than 0.5 percent canopy cover.

G6. — General Description of Paired Stands

Stands 102 and 103 - Old Whitehall Cemetery, approximately 3 miles (5 km) north of Whitehall, Montana, on a slight westerly exposure at 4,600 ft (1,400 m) elevation. Stand 102 was within the fenced cemetery and had probably been protected from grazing for at least 30 years; Stand 103 was adjacent to fenced area and apparently received year-round use by horses and cattle. Both stands were probably heavily grazed prior to fencing the cemetery.

Stands 167 and 168 - Near Daisy Dean Creek, 6 miles (10 km) east of Martinsdale, Montana, on a slight southwest exposure at 4,700 ft (1,430 m) elevation. Both stands have a probable history of heavy sheep grazing, but Stand 167, along a road right-of-way, is now subject to only occasional transient use. Stand 168 is in an adjacent pasture which is being at least moderately grazed by cattle.

Stands 107 and 108 - Near the Quinn Creek Church, 10 miles (16 km) southeast of Boulder, on a slight northeast exposure at 4,600 ft (1,400 m) elevation. Stand 107, within the old church driveway, has received negligible use for an undetermined number of years; Stand 108 is currently used by both cattle and horses.

Stands 16 and 17 - The old Rochester Cemetery, 20 miles (32 km) west of Twin Bridges, on a 10 percent easterly exposure at 5,800 ft (1,770 m) elevation. Stand 16 is within the cemetery exclosure and probably has not been grazed appreciably for the past 70 years. Stand 17, just outside of the fence, is currently used by cattle and no doubt was heavily grazed by horses, cattle, and sheep in the past.

Stands 12 and 13 - On Red Bluff Ranch, 2 miles (3 km) east of Norris, on a 5 percent westerly exposure at 5,000 ft (1,520 m) elevation. Prior to 1950, both stands were probably heavily grazed by sheep. Currently, Stand 13 is moderately grazed and Stand 12 heavily grazed by cattle and horses.

Stands 194 and 195 - Oka Coulee Water Catchment Exclosure, 5 miles (8 km) northwes of Judith Gap, on a 15 percent west exposure at 5,100 ft (1,550 m) elevation. Stand 194 is inside the exclosure and has been protected from grazing for about 10 years; Stand 195 is outside the exclosure and is grazed by cattle. Both areas were probably heavily grazed by sheep in the past.

Stands 232 and 233 - Near Bowman's Corner, 20 miles (32 km) southeast of Augusta, on an 8 percent north exposure at an elevation of 4,700 ft (1,430 m). Stand 232 is along the highway right-of-way with no current livestock grazing. Stand 233 is in an adjacent pasture which receives moderate to heavy cattle use.

Stands 87 and 88 - Along the Mullan Gulch road, approximately 7 miles (11 km) northwest of Deerlodge, on a 10 percent southwest exposure at 5,200 ft (1,580 m) elevation. Stand 87 is along the road right-of-way which receives only transient cattle grazing. Stand 88 is in an adjacent pasture moderately grazed by cattle. Elk and deer use both stands.

Stands 366 and 367 - Near the entrance of the Sun River Game Range, 17 miles (27 k northwest of Augusta, on a 4 percent north exposure at 4,800 ft (1,460 m) elevation. Stand 366 has been virtually protected for about 25 years, having received only light horse use. Stand 367 is in an adjacent pasture heavily used by cattle.

Stands 330 and 331 - On Square Butte, about 7 miles (11 km) southwest of Sun River, on a 3 percent west exposure at 4,300 ft (1,310 m) elevation. Stand 330 is within an exclosure constructed about 1960; it received only incidental use before then because of lack of water. Stand 331 is just outside of the exclosure and has been grazed by cattle for about 12 years.

Stands 337 and 338 - A fenceline comparison along Willow Creek, 16 miles (26 km) northeast of Sunburst, on a 7 percent southwest exposure at 4,200 ft (1,280 m) elevation. Stand 337 is on an area slightly grazed by cattle and sheep; Stand 338 is in an adjacent pasture heavily grazed by cattle.

Stands 198 and 199 - The Flagstaff Exclosure, 16 miles (26 km) southeast of White Sulphur Springs, on 3 percent east exposure at an elevation of 5,700 ft (1,740 m). Stand 198 is inside the exclosure (established 1950) and, except for some elk and deer use, not grazed for 23 years. Stand 199 is immediately outside the exclosure on moderately grazed cattle range.

Stands 37 and 38 - The Eagle Basin Exclosure, about 10 miles (16 km) west of Townsend, on a 25 percent southern exposure at 7,000 ft (2,130 m) elevation. Stand 37 is inside the exclosure, fenced in 1934. Stand 38 is immediately adjacent to the exclosure on moderately used cattle range.

Stands 241 and 242 - The Gibbons Road Exclosure, 5 miles (8 km) southeast of Sula, on a 33 percent west exposure at 6,000 ft (1,830 m) elevation. Stand 241 is within the exclosure established in 1958 and thus protected from grazing for 15 years. Stand 242 is next to the exclosure and grazed moderately to heavily by cattle. This area was part of a sheep allotment in the 1930's.

Stands 163 and 164 - The Flat Iron Ridge Exclosure, 3 miles (5 km) southeast of White Sulphur Springs, on a 2 percent north exposure at 5,800 ft (1,770 m) elevation. Stand 163 is within the exclosure constructed in 1953. The area was probably heavily grazed by sheep in the past, but has received only light deer and trespass cattle grazing for the past 20 years. Stand 164 is next to the exclosure on moderately grazed cattle range.

Stands 105 and 106 - The Hadley Park Exclosure, 9 miles (14 km) south of Boulder, on a 15 percent westerly exposure at an elevation of 5,800 ft (1,770 m). Stand 105 is inside of the exclosure and has been protected from grazing by livestock since 1963. Although this area also was probably used fairly heavily by sheep in the past, it is currently used only by elk and deer. Stand 106 is immediately outside of the exclosure on moderately grazed cattle range.

Stands 112 and 113 - The Wall Creek Exclosure, approximately 25 miles (40 km) south of Ennis, on a 12 percent east exposure at an elevation of 6,200 ft (1,890 m). Stand 113 is inside of an exclosure, built in 1964, that excludes both livestock and big game. Stand 112 is on adjacent range currently used moderately by cattle in the summer and by elk and deer in the winter.

Stands 200 and 201 - The Hatfield Mountain Exclosure, 16 miles (26 km) northwest of the Wilsall, on a 14 percent south exposure at 7,000 ft (2,130 m) elevation. Stand 200 has been protected from grazing for 11 years. Stand 201 is outside of the exclosure on moderately to heavily used cattle range.

Stands 176 and 177 - A fenceline contrast near Spotts Gulch, 13 miles (21 km) south of Big Timber, on a 27 percent northwest exposure at 5,700 ft (1,740 m) elevation. Stand 176 currently receives light cattle grazing, some deer use, and is moderately disturbed by rodents. Stand 177 receives moderate to heavy cattle use and some deer use.

Stands 43 and 44 - The Cliff Lake Natural Area, approximately 40 miles (64 km) south of Ennis, on a 3 percent west exposure at 7,000 ft (2,160 m) elevation. Stand 44 is within the natural area which was fenced in 1951; this area had been grazed only lightly by sheep before then. Stand 43 is on adjacent range that has been moderately grazed by cattle for the past 21 years, and only lightly grazed by sheep before then.

Mueggler, W. F. and W. L. Stewart.
1978. Grassland and shrubland habitat types of western Montana. USDA For. Serv. Gen. Tech. Rep. INT-66, 154 p. Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.

A classification system based upon potential natural vegetation is presented for the grasslands and shrublands of the mountainous western third of Montana. The classification was developed by analyzing data from 580 stands. Twenty-nine habitat types in 13 climax series are defined and a diagnostic key provided for field identification. Environment, vegetative composition, forage production, changes with grazing, and range management practices are described for each habitat type.

KEYWORDS: vegetation classification; habitat types; range types; mountain grasslands; Montana; range ecology; range management.

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(high elevation valley bottoms and flood

the herbaceous vegetation . . . .

GRASSLAND AND SHRUBLAND HABITAT TYPES OF WESTERN MONTANA

W.F. Mueggler
W.L. Stewart

Published as part of USDA Forest Service
General Technical Report INT-66

KEY TO MAJOR GRASSLAND AND SHRUBLAND HABITAT TYPES IN WESTERN MONTANA.

talis conspicuous . . . .

FESTUCA IDAHOENSIS/DESCHAMPSIA CAESPITOSA h.t.

filifolia present. . . . . .LIATRIS PUNCTATA phase

americana present. . . . . .STIPA VIRIDULA phase

somewhat more abundant . . . . .ARTEMISIA ARBUSCULA/AGROPYRON SPICATUM h.t.

the dominant shrub . . . . .ARTEMISIA TRIDENTATA/AGROPYRON SPICATUM h.t.

(p 64)

GRASSLAND AND SHRUBLAND HABITAT TYPES OF WESTERN MONTANA

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Figure 2.--*Stipa comata/Bouteloua gracilis* h.t. on a gently-sloping alluvial fan near the valley floor at 5,200 ft. elevation east of Twin Bridges in southwestern Montana.

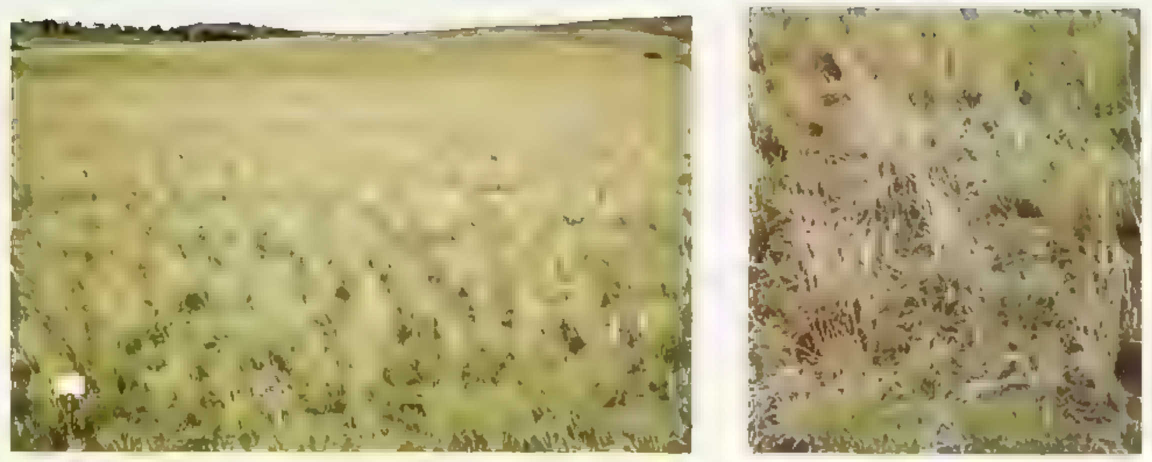

Figure 3.--*Agropyron spicatum/Bouteloua gracilis* h.t. on a gentle west-facing slope, 5,000 ft. elevation, in the foothills west of Bozeman in southwestern Montana.

Figure 4.--*Agropyron spicatum/Agropyron smithii* h.t. on a gentle southwesterly slope, at 5,100 ft. elevation where the plains meet the mountains near Judith Gap in central Montana.

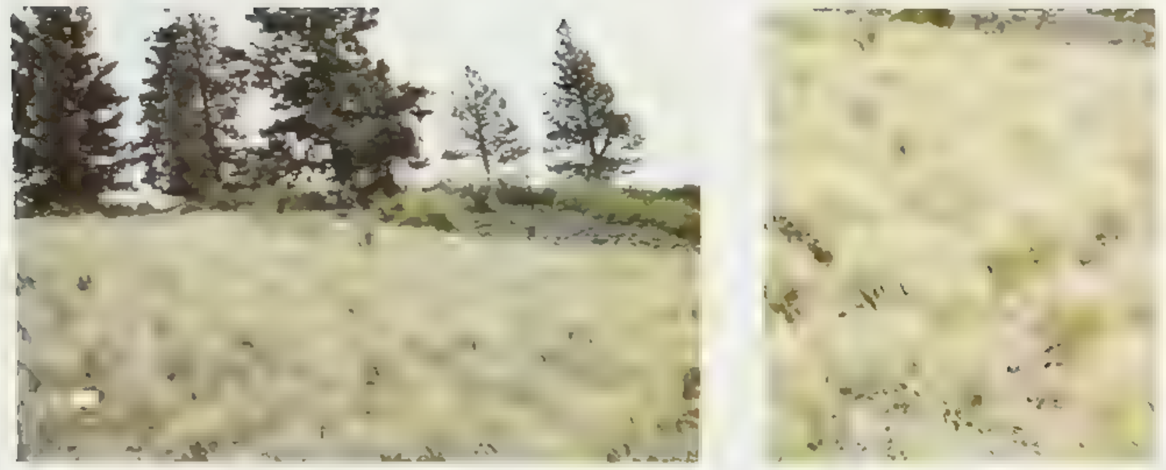

Figure 5.--*Agropyron spicatum/Poa sandbergii* h.t. on a 40 percent southwest slope at 4,200 ft. elevation east of Lonepine in northwestern Montana.

Figure 6.--*Festuca scabrella/Agropyron spicatum* h.t. on a southwest-facing slope, 3,500 ft. elevation, in the foothills west of Flathead Lake in northwestern Montana.

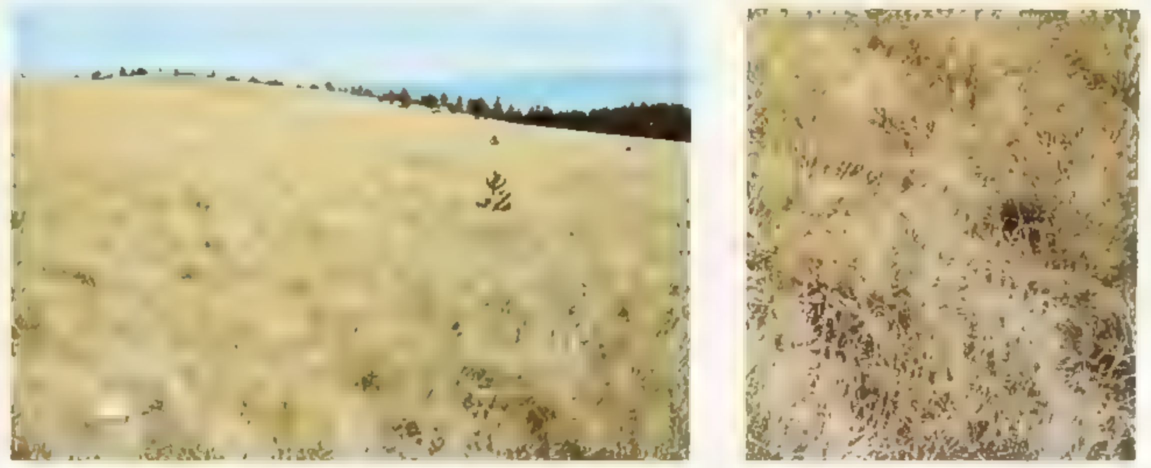

Figure 7.--*Festuca scabrella/Festuca idahoensis* h.t. at 6,400 ft. elevation near McDonald Pass west of Helena, Montana.

Figure 8.--*Festuca idahoensis/Agropyron smithii* h.t. on rolling foothills at 5,100 ft. elevation west of Bozeman in southwestern Montana.

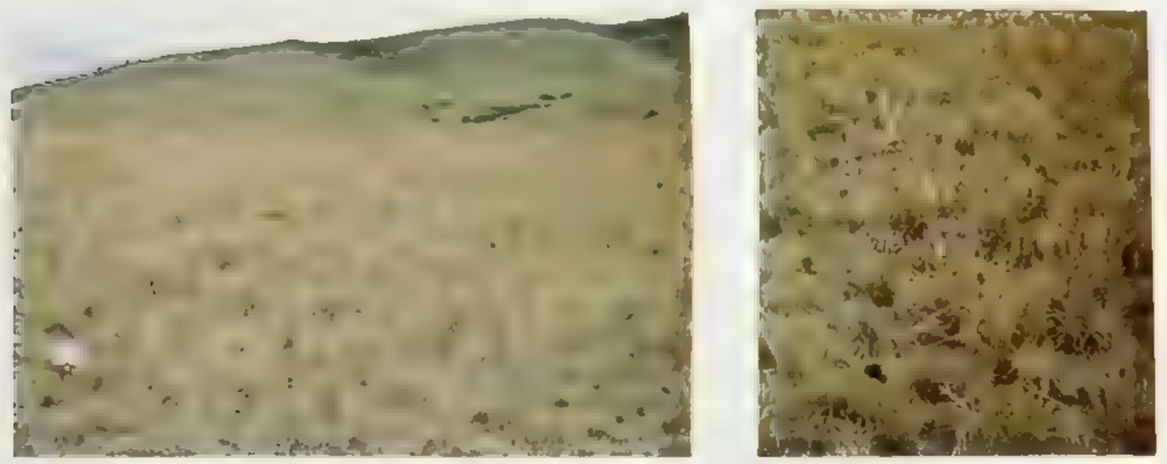

Figure 9.--*Festuca idahoensis/Agropyron spicatum* h.t. on a northwest facing slope, at 5,200 ft. elevation in the foothills west of Bozeman. This is one of the most frequently encountered types in southwestern Montana.

Figure 10.--*Festuca idahoensis/Agropyron caninum* h.t. occurring on deep loessal soils within the Cliff Lake Research Natural Area, 7,100 ft. elevation, in Madison County, southwestern Montana.

Figure 11.--*Festuca idahoensis/Carex filifolia* h.t. occurring on Bull Mountain at 7,900 ft. elevation near Whitehall in southwestern Montana.

Figure 12.--*Festuca idahoensis/Stipa richardsonii* h.t. at 6,880 ft. elevation in Yellowstone National Park

Figure 13.--*Festuca idahoensis/Deschampsia caespitosa* h.t. at 9,250 ft. elevation on top of the Gravelly Range in southwestern Montana.

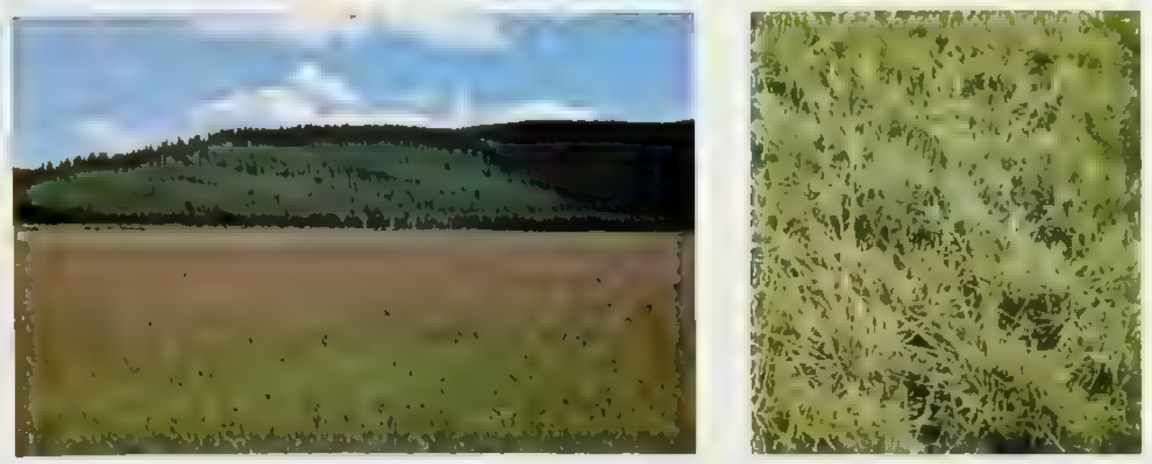

Figure 14.--*Deschampsia caespitosa/Carex* spp. h.t. west of Whitefish in northwestern Montana. This type frequently occupies mountain meadows with poorly-drained soils.

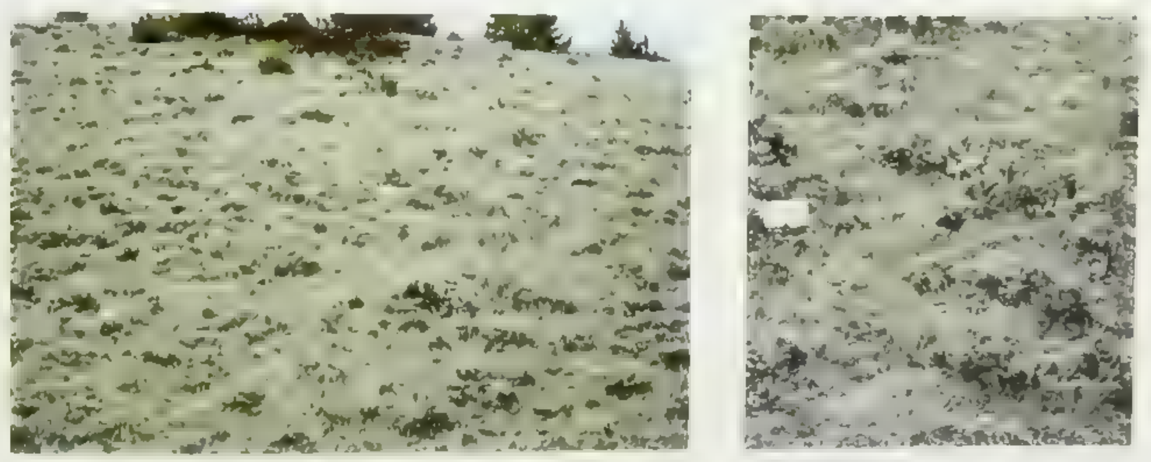

Figure 15.--*Artemisia arbuscula/Festuca idahoensis* h.t. on a north slope at 6,200 ft. elevation near Gardner in southwestern Montana.

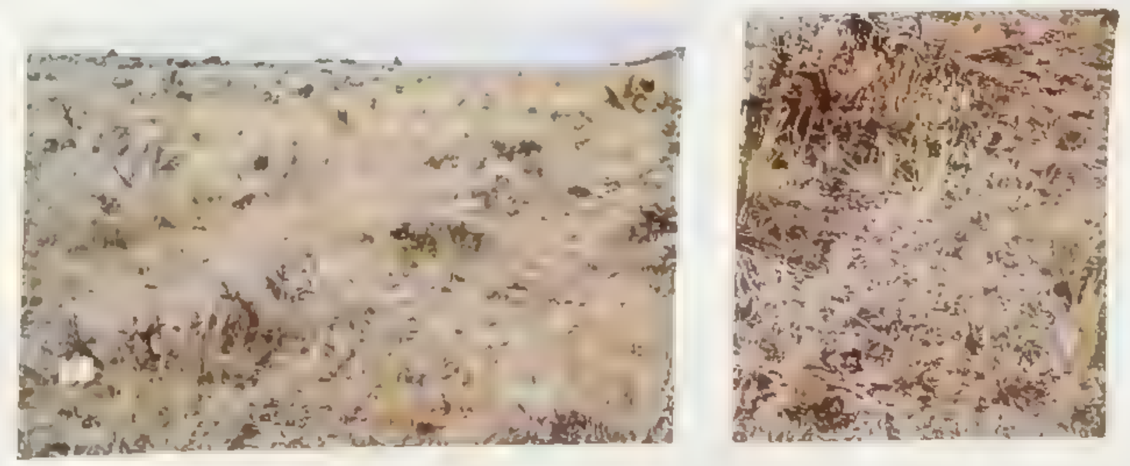

Figure 16.--*Artemisia tridentata/Agropyron spicatum* h.t. at 4,800 ft. elevation in the Limestone Hills west of Townsend, Montana.

Figure 17.--*Artemisia tridentata/Festuca scabrella* h.t. in the Copper Creek Exclosure, 5,900 ft. elevation, north of White Sulphur Springs, Montana.

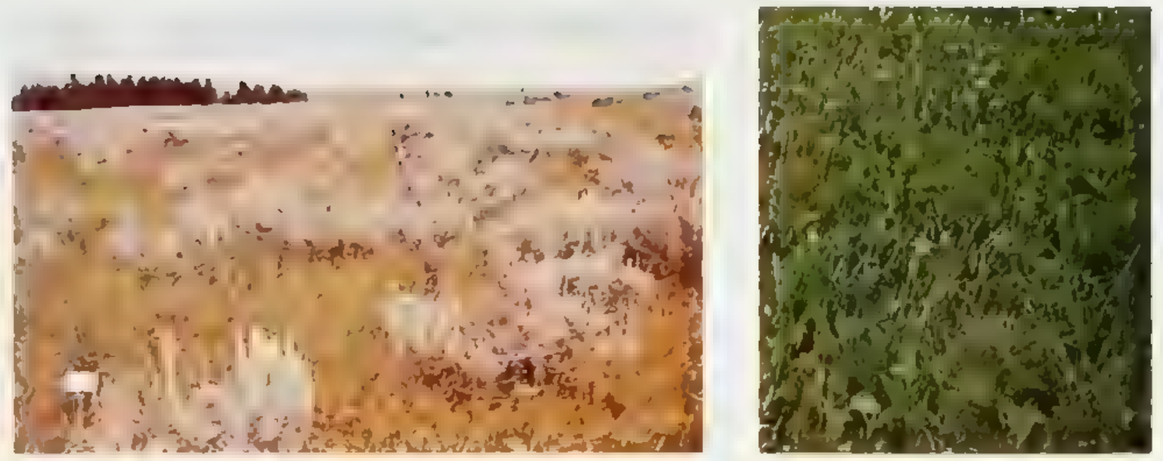

Figure 18.--*Artemisia tridentata/Festuca idahoensis* h.t. on the Cliff Lake Research Natural Area, 7,200 ft. elevation in Madison County, Montana. The scattered, multiaged populations of sagebrush has an abundant understory of grasses and forbs.

Figure 19.--*Artemisia tripartita/Festuca idahoensis* h.t. at 6,900 ft. elevation near Dillon in southwestern Montana.

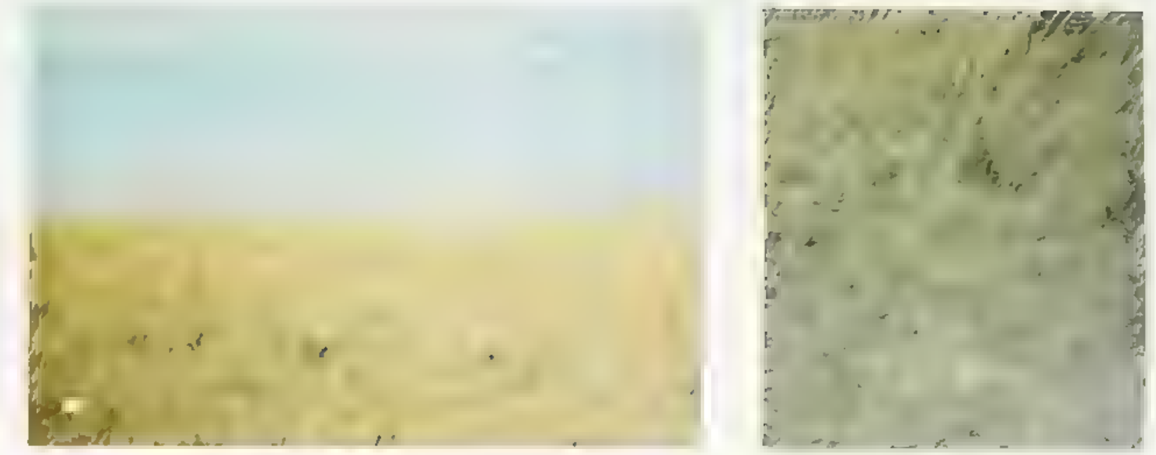

Figure 20.--*Potentilla fruticosa/Festuca scabrella* h.t occurring where the plains meet the mountains, 4,340 ft. elevation, near Dupuyer in northern Montana

Figure 21.--*Potentilla fruticosa/Festuca idahoensis* h.t. at 7,240 ft. elevation on a north exposure near Big Timber in south central Montana.

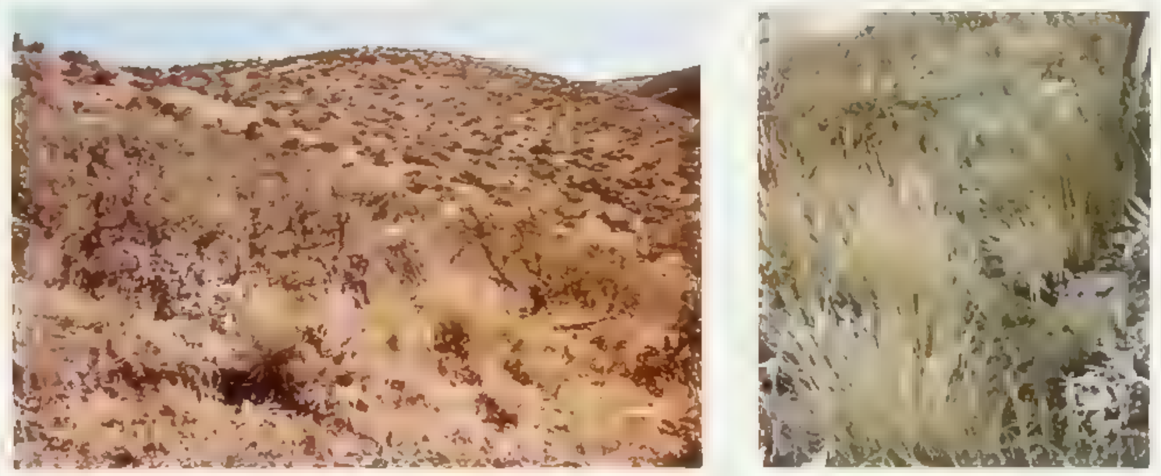

Figure 22.--*Purshia tridentata/Agropyron spicatum* h.t. in the Bitterroot Valley, elevation 4,200 ft., south of Darby. Usually this type does not occur in such extensive stands in Montana.

Figure 23.--*Purshia tridentata/Festuca scabrella* h.t. on a moderately steep southwest slope west of Flathead Lake in northwestern Montana.

Figure 24.--*Purshia tridentata/Festuca idahoensis* h.t. on moderately steep southwest exposure northeast of Deer Lodge. The bitterbrush has been heavily browsed by deer in the winter.

Figure 25.--*Cercocarpus ledifolius/Agropyron spicatum* h.t. on steep limestone slopes near the Lewis and Clark Caverns in southwestern Montana.

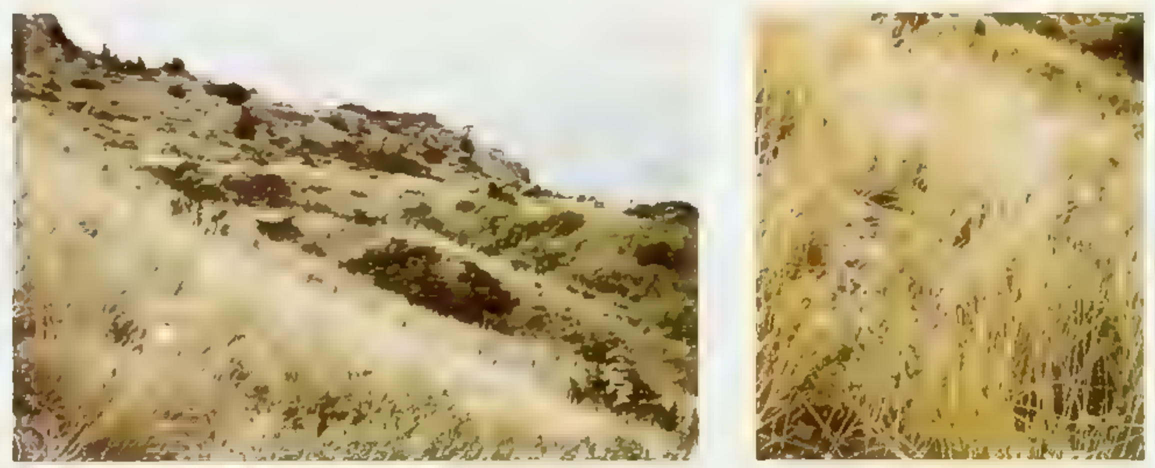

Figure 26.--*Rhus trilobata/Agropyron spicatum* h.t. on a moderately steep south slope along the Yellowstone River near Big Timber in south central Montana.

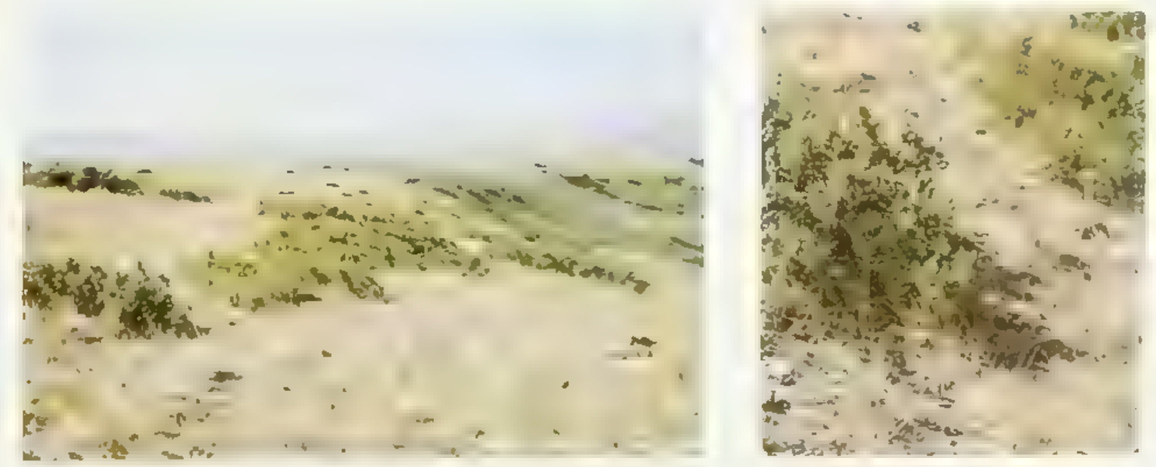

Figure 27.--*Rhus trilobata/Festuca idahoensis* h.t. along the shoulder of benches dropping into the Missouri River southwest of Great Falls, Montana.

Figure 28.--*Sarcobatus vermiculatus/Agropyron smithii* h.t. on alkaline flats west of Great Falls

Figure 29.--*Sarcobatus vermiculatus/Elymus cinereus* h.t. on toe slopes into the Ruby River south of Alder in southwestern Montana.

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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WATER QUALITY IN AN IDAHO STREAM DEGRADED BY ACID MINE WATERS

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RESEARCH SUMMARY

The loss of a valuable salmonid fish population in the Panther Creek drainage of east-central Idaho led to studies designed to identify the source of toxic materials in the drainage. Numerous studies summarized here indicate that water seepage from adits of the no longer operating Blackbird Mine and leaching from mine waste piles are the principal sources of cobalt, copper, iron, manganese, lead, and zinc in the drainage. Downstream from the mined area, pH values have been lowered to levels lethal to aquatic organisms. High sediment loads in area streams are probably the result of stream scouring below the mined area. Sampling of the drainage yielded no fish nor aquatic insects in areas affected by mining. Upstream from mined areas, diverse populations of both fish and insects existed. Tests showed that trout fingerlings placed downstream from the mined area were killed. Elimination of fish populations from waters altered by mining in the Panther Creek drainage is probably the result of the long-term, chronic effects of heavy metal toxicity. Pollution from the mine, waste dumps, and tailings ponds will remain in the drainage until these areas are rehabilitated.

The research reported here was funded by the SEAM program. An acronym for Surface Environment and Mining, SEAM is a Forest Service program to research, develop, and apply technology that will help maintain a quality environment and other surface values while helping to meet the Nation's mineral requirements. The SEAM program is a partnership with land managers, regional planners, mining industries, and political jurisdictions at all levels.

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INTRODUCTION

Acid water discharging from mines into streams is a pollution problem that has destroyed many fish populations throughout the country. The problem first gained prominence in the Eastern United States where large coal mines are operated in acid soils. A similar problem exists in the Western United States, where hard-rock mining exposes sulfide minerals to oxidation and results in the discharge of strong acids and heavy metals detrimental to aquatic life.

Such is the case with the Blackbird Mine on the Salmon National Forest near Salmon, Idaho. Sulfide ores were processed at the mine to isolate copper, cobalt, silver, and gold, and acid mine water resulted. Observations before 1967 seemed to indicate that operations of the Blackbird Mine caused the loss of anadromous and resident fish in the Panther Creek drainage. Later studies (Platts 1967, 1972) disclosed that a valuable resident sport fishery had been depressed and that runs of anadromous fish had been eliminated from the Panther Creek drainage.

From 1967 to 1972, the Forest Service conducted studies in the Panther Creek drainage to identify toxic elements present in the area and their effects on aquatic organisms. From 1972 to the present, additional information was collected by personnel from the Salmon National Forest, the Idaho Department of Health and Welfare, the University of Idaho College of Mines, and the Idaho Department of Fish and Game as part of a continuing program monitoring the Panther Creek drainage.

This report summarizes data from the above sources. Because of the variety of data sources and sample sites, this discussion deals only with trends in the variables, and will serve as a general summary of the pollution situation in the Panther Creek drainage.

The data analysis will provide the land manager with information important to planning. Future studies incorporating this data would allow land managers to evaluate the effectiveness of rehabilitation projects and management decisions, as well as the long-term effects of acid mine water drainage on fish populations.

STUDY AREA DESCRIPTION

The Blackbird Mining District is 25 mi (40 km) southwest of Salmon, Idaho. Blackbird, Meadow, Bucktail, and Big Deer Creeks drain the mined area and flow into Panther Creek. Panther Creek enters the Salmon River about 51 mi (82 km) below Salmon, Idaho. The Panther Creek watershed is approximately 600 mi^2 (1,550 km^2) and ranges in elevation from 3,300 to 10,000 ft (1,000 to 3,040 m). The drainage is characterized by steep mountain slopes and canyons with steep gradients.

The Panther Creek headwaters are in the Belt Series, a geologic formation of Precambrian quartzite and argillite with some intermixtures of calcareous rock and basalt. Downstream from the headwaters, Panther Creek is in the Idaho Batholith, which is composed mainly of decomposing granitic rocks.

The mean discharge of Panther Creek is 248 ft^3/s (421.6 m^3/min). High water runoff begins about April 1 and continues through June (Andreesen 1972). During high flows, flooding often occurs and the potential for stream scour is high. As a consequence, sediments from tailing dumps and waste piles in the mined area are transported downstream and often are redeposited on the flood plains and in channels of lower Blackbird Creek and Panther Creek (Figure 1).

Figure 1.--Sediment in Blackbird Creek below the mill (March 1967).

Blackbird Creek enters Panther Creek 35 mi (57 km) above the mouth of Panther Creek. The elevation of Blackbird Creek ranges from 5,100 to 8,200 ft (1,560 to 2,500 m). Blackbird Creek is over 9 mi (15 km) in length and drains 23 mi^2 (60 km^2) with a mean discharge of 10.0 ft^3/s (70.2 m^3/min). Flow at the mouth varies from a low of 3.5 ft^3/s (5.9 m^3/min) in January to a high of 40.6 ft^3/s (68.9 m^3/min) in June (Andreesen 1972). Farmer (personal communication) has estimated high flows at up to 70 ft^3/s (118 m^3/min).

Mining History

Mining activity in the Blackbird Mining district began in 1893 and has been sporadic since that time. Mining properties have gone through numerous ownerships and are currently controlled by the Idaho Mining Company. All production operations were stopped in 1967. While it was operated, the mine produced copper, gold, and cobalt ores. The Idaho Mining Company as full lease holder recently has been engaged in exploring the property. Future plans call for reopening some underground workings and two new open pit operations in the area.

Water from the mine, waste piles, and portals drains directly into Meadow Creek, a tributary of Blackbird Creek. The Blacktail open pit is located at the headwaters of Bucktail Creek. Bucktail Creek also receives runoff from numerous mine portals and waste piles. This creek is a tributary of Big Deer Creek, which flows into Panther Creek.

The mill is located near the confluence of Blackbird and Meadow Creeks. A coffer dam was built on Blackbird Creek in the 1940's to contain and divert mining wastes. A piping system that parallels Blackbird Creek carries and dumps the waste into a tailings pond on the West Fork of Blackbird Creek. Settling ponds were also constructed on Blackbird Creek immediately upstream from the mouth of the West Fork. During milling operations, frequent leaks and breaks occurred in the conduit system which combined with the water overflow and breaks in the coffer dam. Because the collection facility was ineffective, large amounts of mine waste continued to enter the Blackbird and Panther Creek system (Figures 2 and 3).

Figure 2.--High water heavily laden with mine tailings bypassing the coffer dam on Blackbird Creek (May 1967).

Figure 3.--Acid water seepage from the Blackbird Mine shaft (August 1970).

Since the mine closed in 1967, some restoration work has been done in the drainage. Personnel from the Salmon National Forest did channelization work on Blackbird Creek. In addition, the Intermountain Forest and Range Experiment Station has planted experimental vegetation plots on disturbed mining sites in the Blackbird Creek drainage (Farmer, Richardson, and Brown 1976). Despite these efforts, the mine, waste dumps, and tailings pond continue to pollute Blackbird and Panther Creeks. Waterflow from mine adits and seepage from the tailings pond still heavily pollute the drainage. Spring runoff will continue to scour the waste dumps and stream channels and deposit sediment downstream until the dumps are stabilized (Figure 4).

Figure 4.--The confluence of Blackbird and Panther Creeks showing the high turbidity of Blackbird Creek (September 1969).

History of Fishery

Panther Creek historically served as a spawning and nursery area for chinook salmon [*Onocorhynchus tshawytscha* (Walbaum)] and steelhead trout [*Salmo gairdneri* (Richardson)] and as residential waters for trout and mountain whitefish [*Prosopium williamsoni* (Girard)]. Local residents reported that chinook salmon and steelhead trout were numerous in Panther Creek before 1945 (Corley 1967). Idaho Department of Fish and Game records show that a large fish kill occurred in Panther Creek during March, April, and July, of 1954. Among the dead fish were 200 adult chinook salmon, steelhead and resident trout, and whitefish. Fish and Game redd counts in 1954 confirm use of Panther Creek by chinook salmon. In 1957, the number of salmon redds counted came to 135; in 1962, only 13 adult chinook salmon spawned near the mouth of Porphyry Creek, a tributary of Panther Creek above Blackbird Creek (Pence 1966). Electrofishing by Corley (1967) identified rainbow trout [*Salmo gairdneri* (Richardson)], eastern brook trout [*Salvelinus fontinalis* (Mitchell)], mountain whitefish, sculpin (*Cottus* sp.), longnose dace [*Rhinichthys cataractae* (Valenciennes)], and suckers (*Catostomus* sp.) in the drainage. Pence (1966) added Dolly Varden [*Salvelinus malma* (Walbaum)] and cutthroat trout [*Salmo clarki* (Richardson)] to this list.

Aquatic Insects

Panther Creek was used by diverse families of insects for oviposition, nymph development, and larval metamorphosis. Panther Creek bottom samples contained populations of four insect orders, all commonly used as food by salmon and trout (Corley 1967). They were: (1) midges (Diptera); (2) caddisflies (Trichoptera); (3) mayflies (Ephemeroptera); and (4) stoneflies (Plecoptera).

METHODS

Water Chemistry Sampling

Sampling procedures followed those outlined in Standard Methods for the Examination of Water and Waste water (1971). Intermountain Forest and Range Experiment Station personnel sampled 23 stations in the Panther Creek drainage from 1967 through 1970. From 1974 through 1976, researchers from the University of Idaho College of Mines sampled 27 stations in the area. Stations sampled were:

Forest Service stations	Location
1B	Blackbird Creek--above mill
2B	Blackbird Creek--below mill
3B	West Fork Blackbird Creek--above tailings pile
4B	West Fork Blackbird Creek--below tailings pile
5B	Blackbird Creek--mouth of Blackbird Creek
8B	Slippery Creek--above confluence, Blackbird Creek
9B	Ludwig Creek--above confluence, Backbird Creek
10B	Blackbird Creek--Mine discharge water--6,850 portal
11B	Meadow Creek--immediately above mill
12B	Meadow Creek--between St. Joe portal and Blackbird Creek
13B	Meadow Creek--1-1/2 miles upstream from mouth
14B	Meadow Creek--above mining activity
1P	Panther Creek--below confluence, Moyer Creek
2P	Copper Creek--above confluence, Panther Creek
3P	Panther Creek--above confluence, Napias Creek
4P	Panther Creek--above confluence, Little Deer Creek
5P	Little Deer Creek--above confluence, Panther Creek
6P	Big Deer Creek--above confluence, Panther Creek
7P	Panther Creek--Rams Point Campground
8P	Panther Creek--above confluence, Salmon River
9P	Salmon River--above confluence, Panther Creek
10P	Panther Creek--above confluence, Blackbird Creek
11P	Panther Creek--below confluence, Blackbird Creek

University of Idaho stations	Location
1	Blackbird Creek--below mouth of West Fork
2	West Fork Blackbird Creek--below tailings pile
3	West Fork Blackbird Creek--above tailings pile
4	Blackbird Creek--above mouth of West Fork
5	Slippery Creek--mouth of Slippery Creek
6	Blackbird Creek--below mill
7	Blackbird Creek--mine discharge water, 6,850 portal
8	Blackbird Creek--above mill
9	Meadow Creek--below St. Joe portal
10	Meadow Creek--below 7,100 waste pile
11	Meadow Creek--below mouth of Spring Creek
12	Spring Creek--mouth of Spring Creek
13	Meadow Creek--1-1/2 miles upstream from mouth
14	Meadow Creek--2 miles upstream from mouth
15	Meadow Creek--7,400 portal
16	Meadow Creek--above mined area
17	Meadow Creek--below Forest Service waste pile
19	Bucktail Creek--below Blacktail Pit
20	Bucktail Creek--7,265 portal
21	Bucktail Creek--below 7,265 portal
22	Bucktail Creek--7,117 portal
23	Bucktail Creek--1-1/2 miles upstream from mouth
24	Bucktail Creek--mouth of Bucktail Creek
25	South Fork Big Deer Creek--above mouth of Bucktail Creek
26	South Fork Big Deer Creek--below mouth of Bucktail Creek
27	South Fork Big Deer Creek--mouth of South Fork Big Deer Creek
28	Big Deer Creek--below mouth of South Fork of Big Deer Creek

This report also presents data from recent collections at seven sites on Meadow and Blackbird Creek made by personnel from the Salmon National Forest. Although some of the sites were duplicated in the sampling program, a total of 47 different sites were sampled (fig. 5).

Water samples were collected in polyethylene bottles that had been rinsed with acid and cleansed with hot distilled water. For the 1967-1970 study, two samples were collected at each station, a 4-oz (115-ml) sample for heavy metal analysis and a 16-oz (450-ml) sample for the remainder of the tests. For the heavy metal analyses, the 4-oz (115-ml) bottle was acidified with 0.04 oz (1 ml) of nitric acid. Samples were either delivered immediately to the laboratory or were frozen for later analysis. Water was analyzed for total solids, total dissolved solids, copper, iron, cobalt, silver, arsenic, boron, cadmium, calcium, chlorine, chromium, fluorine, mercury, potassium, magnesium, manganese, sodium, nitrate, lead, sulfate, zinc, nickel, phosphate, hardness, and alkalinity. Analyses were conducted according to procedures outlined in Standard Methods for the Examination of Water and Wastewater (1971). Water samples were analyzed by chemists at the Idaho State Department of Health and Welfare Laboratory in Boise, Idaho, and the Environmental Protection Agency, Pacific Northwest Water Laboratory, Corvallis, Oregon. Samples collected by University of Idaho personnel were not acidified. These were analyzed at laboratory facilities provided by the Idaho Mining Company at Cobalt, Idaho. A Hach portable chemical analysis kit was used in the field to analyze dissolved oxygen and pH. An Imhoff cone was used in the field to analyze suspended sediment.

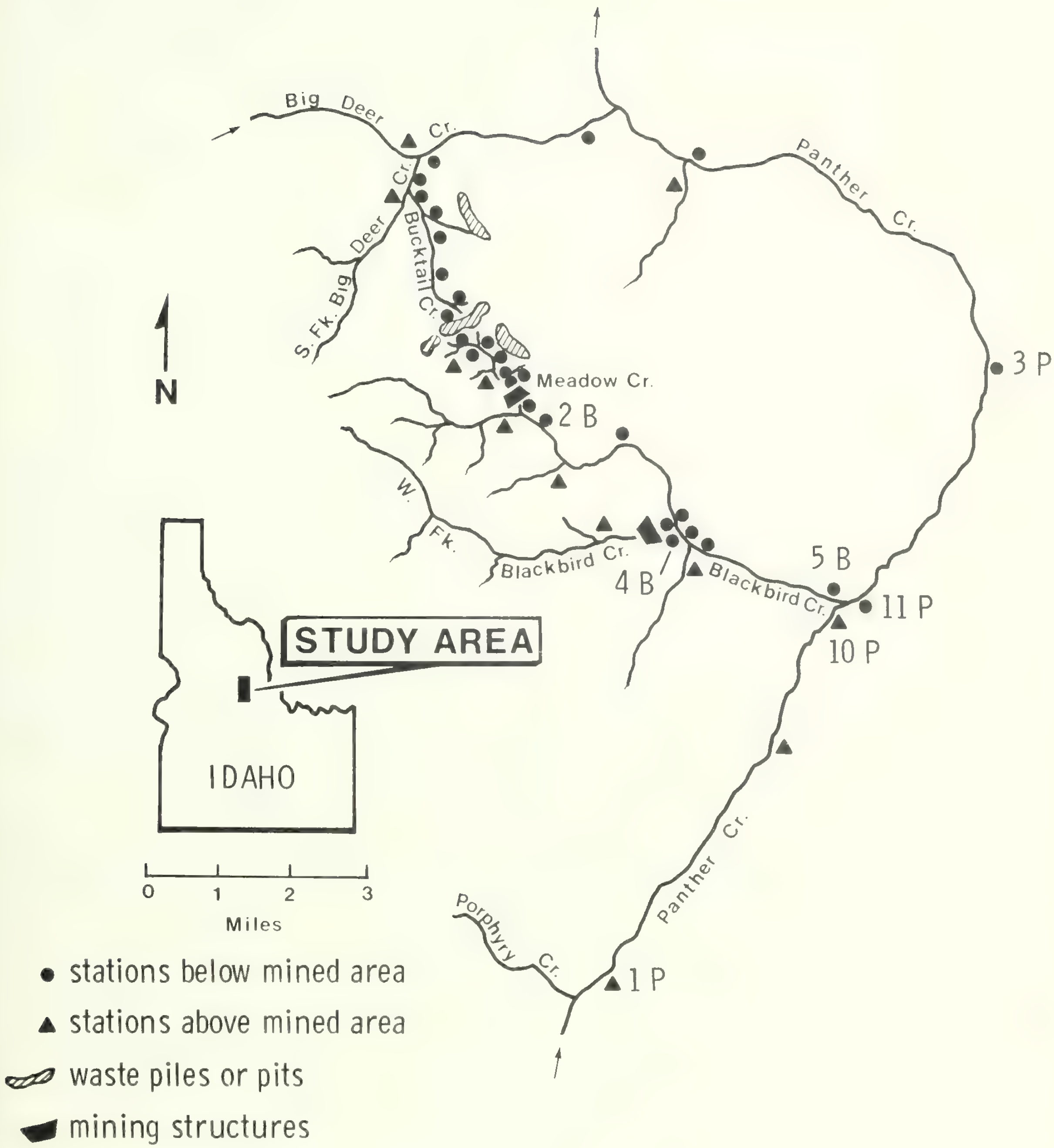

Figure 5.--Sample sites in the Panther Creek drainage.

Channel substrate samples were taken with a 6-in (152-mm) diameter core sampler designed by McNeil (1964). Core samples were analyzed in the Forest Service Materials Laboratory, Intermountain Region, Salt Lake City, Utah, by heat drying and straining the materials through sieves. The amount of fine sediment (mainly clays) passing through the smallest sieve size was determined by hydrometric analysis. Other sediment size class amounts were determined by direct weighting.

Biological Sampling

AQUATIC INSECTS

In 1967, Corley sampled aquatic insect populations at four Panther Creek stations. At each station, five 2-ft^2 (0.19-m^2) benthic samples were taken. A circular frame covered with window screen (14 mesh per inch [6 mesh per cm]) was used to collect insects dislodged from the stream bottom. The insects were placed in glass vials and preserved for analysis of number and order.

FISH POPULATION

Fish populations were sampled with an electrofisher at five Panther Creek stations and one Blackbird Creek station in 1967.

FINGERLING TROUT

One hundred rainbow trout fingerlings, averaging 3 inches (7.7 cm) in length, were placed in one of two "live" boxes (Corley 1967). The boxes were 1.5 by 2 by 3 ft (46 by 61 by 91 cm) in dimension, and were covered by a 1/4-inch (0.64-cm) mesh hardware cloth. The boxes were placed in at least 1 ft (30 cm) of water at three Panther Creek stations. After 3 days, the fish were checked for survival.

RESULTS AND DISCUSSION

Water Chemistry

For easy discussion of water quality in the Blackbird Mining District, data in this report are presented as being collected upstream or downstream from the mined area. Sites upstream from the mining district receive no pollutants from the mined area, while those downstream are subject to input from the mine and its portals, open pits, waste piles, tailings ponds, and any water seepage from these sources. Selected results from the water chemistry testing are given in Table 1. These data are for the most extensively tested variables and readily reflect any mining-related pollution in the drainage. Tables 2 and 3 present a summary of the data by sample site. Although mean concentrations of heavy metals appear to decrease at the sample sites farthest downstream from the mined area, concentrations generally remain higher than natural background levels.

Table 1.--*Mean concentrations of selected water chemistry variables in the Blackbird mining area, 1966 to 1977. Sample size in parenthesis*

Sample sites	Variable											
	pH range	Alkalinity	Hardness	Cobalt	Copper	Iron	Lead	Manganese	Zinc	Suspended solids	Dissolved solids	Total solids
						[illegible]						
Upstream from mined area	3.4-8.5 (29)	52.2 (7)	87.1 (19)	0.29 (11)	0.26 (31)	0.6 (45)	0.04 (12)	0.6 (20)	0.03 (14)	12.4 (18)	182 (16)	140 (19)
Downstream from mined area	2.7-8.5 (74)	34.8 (33)	100 (28)	26.3 (59)	76.3 (100)	19.2 (100)	0.03 (29)	6.5 (70)	0.07 (31)	52.9 (22)	185.6 (25)	275.4 (29)

Note: mg/liter are equivalent to parts per million (ppm)

Table 2.--*Summary of selected data from Forest Service sample stations in the Panther Creek drainage, 1966 to 1977*

Station	Variable						
	pH range	Cobalt	Copper	Iron	Lead	Manganese	Zinc
				mg/liter			
1B	7.0	--	0.05	0.1	--	--	--
2B	3.2-3.4	--	5.8	11.8	<0.01	1.3	0.007
3B	--	--	.01	.09	<.01	.01	<.001
4B	5.3-6.9	--	.2	.7	<.01	.26	.006
5B	5.3-6.9	--	1.3	8.9	<.01	.76	.06
8B	--	--	.01	.15	--	--	--
9B	--	--	.03	.12	--	--	--
10B	2.7	--	13.5	71.5	.06	14.1	.2
11B	--	--	16.7	21.8	<.01	3.4	.1
13B	--	--	11.5	5.2	--	--	--
14B	--	--	.2	.1	--	--	--
1P	7.3-8.3	0.009	.009	.2	--	.01	.02
2P	8.0-8.3	.006	.01	.1	<.01	.006	.01
3P	8.4	--	.4	1.4	.01	.09	.02
4P	8.5	--	.08	.8	.01	.05	.02
5P	--	.04	--	.05	.07	.02	.04
6P	8.4	.18	.17	.2	.01	.02	.01
7P	8.4	.26	.009	.7	.01	.04	.02
8P	7.5-8.4	.18	.08	.5	.01	.04	.01
9P	7.4-8.5	--	.03	.7	<.005	.04	.01
10P	8.0-8.4	.005	.009	.2	.01	3.3	.01
11P	6.5-8.2	.4	.09	1.0	.01	.07	.1

Note: mg/l are equivalent to parts per million (ppm)

Table 3.--*Summary of selected data from University of Idaho sample stations in the Panther Creek drainage, 1974 to 1976*

Station	Variable				
	pH range	Cobalt	Copper	Iron	Manganese
		- - - - - - - - - - -*mg/liter*- - - - - - - - - - -			
1	3.7-4.9	1.6	2.4	0.8	0.9
2	2.9-7.3	1.4	.05	5.0	4.0
3	4.0-7.5	.3	.1	.6	.1
4	3.0-4.7	2.4	3.0	2.9	.9
5	3.8-6.0	.7	.1	.3	.3
6	3.1-5.1	3.8	8.8	4.9	2.7
7	2.2-4.2	22.8	54.6	245.0	7.9
8	4.4-7.5	.6	.1	.7	.5
9	2.7-3.6	20.2	14.2	28.0	3.8
10	2.4-4.1	21.7	44.9	27.4	3.7
11	2.9-3.4	9.5	21.2	4.6	1.9
12	3.4-7.3	.3	1.8	2.9	.3
13	3.0-3.3	13.5	24.9	5.0	2.9
14	3.4-5.2	6.7	15.6	.9	.8
15	2.6-3.0	42.3	151.9	78.2	11.8
16	4.6-7.0	.5	.3	.3	.3
17	3.5-4.3	59.1	290.0	.7	11.0
19	3.5-4.6	208.0	1384.9	17.5	29.7
20	2.6-12.0	82.7	111.9	99.6	22.9
21	2.8-4.2	136.0	850.9	44.4	36.7
22	2.8-3.2	24.6	17.8	21.9	9.9
23	3.1-4.4	54.0	270.0	7.6	9.1
24	4.3-5.3	11.3	33.1	.3	1.4
25	5.3-7.8	.03	.03	.2	.3
26	5.4-7.2	1.3	2.5	.1	.3
27	5.5-7.4	.1	.0	.2	.3
28	3.9-6.9	.4	.4	.1	.1

Note: mg/l are equivalent to parts per million (ppm)

The results of statistical F-tests made on the data showed that significant differences (P = 0.05) occurred between sample mean values upstream and downstream from the mined area. Mean values for cobalt, copper, iron, manganese, zinc, and suspended and total solids were found to be significantly greater below the mining district than above it. Differences in levels of alkalinity, hardness, lead, and dissolved solids were not statistically significant.[1] A complete collection of the data summarized in this study is on file at the Intermountain Station's Research Laboratory in Boise, Idaho.

COBALT

Trace amounts of cobalt ions appear to stimulate growth of some organisms (McKee and Wolf 1971). Cobalt concentrations of up to 1.0 mg/liter were not harmful to 1-year-old tench, carp, rainbow trout, and char, nor to the crustaceans, worms and insect larvae that are the food of these fish (Schweiger 1961); however, at higher concentrations, cobalt ions have been toxic. The mean concentration (26.3 mg/liter) of cobalt below the mining influence in the Panther Creek drainage was well above 10 mg/liter, a concentration lethal to sticklebacks (Jones 1939).

[1]The sampling schedule for all other variables was sporadic; so any analysis would be difficult.

COPPER

Copper has been well documented as an aquatic pollutant. The U.S. Public Health Service allows 1.0 mg/liter copper in domestic drinking water, a limit that was set primarily because of the bad taste that develops above this level (U.S. Public Health Service 1962). The California State Water Control Board has recommended an allowable maximum concentration of 0.02 mg/liter of copper in waters inhabited by fish and other aquatic life (McKee and Wolf 1971). This allowable level is exceeded in the Panther Creek drainage even in the waters above the mined area (0.26 mg/liter copper), but this may reflect some sampling or analytical errors. High levels of copper may be tolerated by aquatic organisms for a short period, provided they are not subjected to stress from other factors. Downstream from the mined area, the mean copper concentration was about 300 times greater (76.3 mg/liter) than that found upstream (0.26 mg/liter). This concentration virtually guarantees that no aquatic organism will survive in this area (Wilson 1972). A more detailed discussion of effects of copper on the aquatic biota appears in the section on biological components.

IRON

According to Ellis (1940), 95 percent of the waters in the United States that support good fish populations have iron concentrations of 0.7 mg/liter or less. Iron concentrations higher than 1 to 2 mg/liters are indicators of acid pollution (Ellis and others 1946). Mean concentrations of iron in stream sections above the Panther Creek mining district were suitable for survival of aquatic life (0.6 mg/liter).

The toxicity of iron appears to result from the action of specific iron salts or from the precipitate that forms from the combination of iron and hydroxyl ions. Fish apparently are killed by coatings of iron oxide or hydroxide precipitates on the gills (van Duijn 1967). In addition, Sykora and others (1972) found a definite trend toward smaller juvenile brook trout when fish were exposed to ferric hydroxide for a long period. They suggested that the precipitate impaired visibility, which caused feeding difficulties and resulted in slower growth. In well-aearated waters, ferrous ions may oxidize to ferric ions, which readily form insoluble hydroxides. If the pH and oxidation-reduction potential of the waters do not favor such compounds, high concentrations of iron ions may remain in solution (Hem and Cropper 1959). The mean iron concentrations (19.2 mg/liter) in the Panther Creek drainage below the mined area were definitely toxic.

MANGANESE

Manganese is essential to both plant and animal nutrition. To insure good taste, limits in drinking water have been set at 0.05 mg/liter (McKee and Wolf 1971). Jones (1939) gave 40 mg/liter as the lethal concentration of manganese for the stickleback (*Gasterosteus* sp.). Permanganates, which are unstable in water, are lethal to fish at lower levels ranging from 2.2 to 4.1 mg/liter (Iwao 1960). Manganese at levels found in the Panther Creek drainage might not poison aquatic organisms, but may contribute to synergistic toxicity reactions. This situation arises when two or more heavy metals at tolerable levels act in concert to produce a toxic reaction in organisms. Synergism is a common problem with heavy metals.

LEAD

The toxicity of lead alone probably is slight in the study area. The mean levels of 0.04 to 0.03 mg/liter lead upstream and downstream from the mined area are well below the documented toxicity levels. For example, rainbow trout in soft water were

killed at lead concentrations of 1.0 mg/liter (Brown 1968). Carpenter (1927) found fish were killed in lead concentrations of 0.3 mg/liter, a concentration at least 10 times greater than the mean concentrations in the drainage. However, lead is another element that may react with other metals to produce a combined toxicity greater than their individual concentrations.

ZINC

Mean zinc concentrations in the study area apparently were below levels toxic to aquatic organisms. Fish mortalitites usually do not occur at zinc concentrations below 0.3 mg/liter, even in soft waters that have a hardness of 10 mg/liter or less (Sprague 1964a). Since the waters in the Panther Creek drainage range from 87.1 to 100 mg/liter hardness, some protection against zinc toxicity can be expected: however, zinc concentrations in waters downstream from the mining district could be a problem because of zinc's synergistic activity with copper, a metal already present in toxic quantities.

pH

Water samples from sites downstream from the mined area had consistently lower pH values than those upstream (table 1). Generally, a favorable pH range for fish is from 6.5 to 8.7 (U.S. Environmental Protection Agency 1976). Levels below that range can be tolerated without biological damage for short periods, provided the level is attributable to natural organic acids (McKee and Wolf 1971). In streams influenced by mining, a low pH usually indicates the presence of inorganic sulfuric acid, which is involved in the oxidation of ferrous sulfate to ferric sulfate, a soluble toxic form of iron. Ferric sulfate also reacts to free inactive copper in chalcopyrite to form toxic copper sulfate. Both compounds are highly toxic to aquatic organisms.

SEDIMENT

Sediment sampling from 1966 to 1968 showed that a large quantity of fine sediment in Blackbird and Panther Creeks was seriously degrading water quality and channel substrate. Much of the sediment was directly attributed to past operations at Blackbird Mill. Over the 2-year period, selected water samples were taken from five stations downstream from the mined area in the Panther Creek drainage. Samples contained from 400 to 60,900 mg/liter suspended solids. Samples taken for the same study from a station upstream from the mining district showed 0 mg/liter suspended solids.

A particle size analysis of stream channel materials in Blackbird and Panther Creeks indicated that much of the fine sediment deposited during 1968 was from previous Blackbird mining and milling operations. Channel sediment particle size was drastically reduced below the input of the mine and waste piles. Average particle size of channel material collected from selected sites in the Panther Creek drainage was as follows:

Stations	Particle size
	mm
10P (Upstream from mined area)	22.4
11P (Downstream from mined area)	0.22
2B (")	5.78
4B (")	3.50

The large quantities of suspended solids downstream from the mined area would have caused high mortality among salmonid embryos and fry existing in these areas. Fine sediment in the quantities recorded reduces the permeability of spawning gravels and blocks the interchange of subsurface and surface water (Cooper 1959; Koski 1966; McNeil 1964; Vaux 1962).

The mean concentration of total solids at sites downstream from mined areas was significantly higher (275.4 mg/liter) than it was upstream from the mining district (140 mg/liter) (table 1). Damage to the aquatic environment from increased turbidity is direct; photosynthesis is reduced because of light reduction and high amounts of suspended solids interfere with efficient respiration of gilled animals (Coker 1968). Young salmoids are particularly susceptible to gill irritation caused by turbid water, which then exposes them to infection by fungi and bacteria (Bell 1973).

Biological Sampling

AQUATIC INSECTS

Corley's (1967) insect sampling clearly showed the effects the Blackbird Mine has had on aquatic organisms in the area (table 4). Station 1P, the station farthest upstream from the mined area had the greatest number of insects per unit area of streambed. Station 10P, also upstream from mine water input had slightly lower average numbers of insects than station P. Downstream from the confluence of Blackbird and Panther Creeks there were either no insects or a low number of insects (fig. 6). The insect that first reappeared in Panther Creek below the mouth of Blackbird Creek was the midge, which is tolerant of high copper concentrations (up to 2.2 mg/liter) (Surber 1959). Some caddisfly larvae may be equally tolerant of heavy metal pollution (Sprague and others 1965). Most mayfly nymphs cannot survive in streams with heavy metal concentrations far below concentrations lethal to trout (McKee and Wolf 1971). For example, Warnick and Bell (1969) found 0.3 mg/liter iron toxic to mayflies, stoneflies, and caddisflies. Fish populations, however, may tolerate iron concentrations up to 1.0 mg/liter (Ellis 1940). These figures indicate the highly sensitive nature of aquatic insects to heavy metal pollution.

Table 4.--*The mean number of aquatic insects in bottom samples collected from Panther Creek (Corley 1967)*

Insects	Stations: Upstream from mined area		Downstream from mined area	
	1P	10P	11P	3P
Midge (Diptera)	26.8	10.0	0	0.6
Caddisfly (Trichoptera)	15.1	3.6	0	.0
Mayfly (Ephemeroptera)	3.0	6.6	0	.0
Stonefly (Plecoptera)	2.0	3.8	0	.0
Bug (Hemiptera)	.5	.0	0	.0
Beetle (Coleoptera)	.0	.0	0	.4
Unidentified	.0	.0	0	.4
Total	47.4	24.0	0	1.4

Figure 6.--Stream channel rubble from Panther Creek below the confluence with Blackbird Creek showing a lack of aquatic insects and a heavy sediment coat (March 1966.)

In 1976 and 1977, Mangum (1978) sampled macroinvertebrates, water chemistry, and sediment concentrations at six stations in the Panther Creek drainage. Above the confluence of Blackbird and Panther Creeks, he found a healthy insect community typical of high mountain cold water streams in which sedimentation is moderately excessive. Insect diversity at the site was excellent and biomass was good. The insect community was dominated by clean water species (mayflies, stoneflies, and caddisflies). At five stations below the confluence, however, insect diversity was never rated better than poor. Biomass generally ranged from poor to fair, even at downstream sites far from the confluence. At sites below the confluence, insect communities were generally dominated by "drift through" organisms and by pollution-tolerant chironomids and dipterans. Apparently, downstream dilution of the discharge from the Blackbird mine is not great enough to allow recovery of aquatic macroinvertebrates in the drainage.

FISH POPULATIONS

From 1954 to 1967, the annual chinook salmon redd count conducted by the Idaho Department of Fish and Game indicated that spawning populations of chinook salmon had been eliminated from the Panther Creek drainage. From 1963 to 1967, no salmon redds were found, although from 1954 to 1962 an average of 51 redds per year were observed. Official counts were discontinued after 1967, but no redds were seen during field checks from 1968 to 1977.

Electrofishing yielded the highest numbers and variety of species of fish at station 1P, the site on Panther Creek most upstream from the mouth of Blackbird Creek (table 5). At station 10P, nearer the confluence of Blackbird and Panther Creeks, both numbers and species of fish were reduced. No fish were found at station 11P, immediately downstream from the confluence. Farther downstream at station 3P, a few fish, representing only two species were detected. Sampling at the mouth of Blackbird Creek (station 5B) indicated that no fish were present, as did spot checks in Blackbird Creek itself.

Table 5.--*Number of fish by species found at selected sample sites in the Panther Creek drainage (Corley 1967)*

Species	Station upstream from mined area		Station downstream from mined area		
	1P	10P	11P	3P	5B
Rainbow trout	26	20	0	8	0
Eastern brook trout	3	2	0	1	0
Whitefish	27	0	0	0	0
Sculpin	2	0	0	0	0
Dace	3	0	0	0	0
Unidentified	5	2	0	0	0
Total	66	24	0	9	0

Few if any fish in a stream can suggest fish avoidance of undesirable conditions rather than toxic concentrations of heavy metals. Absence of fish could also suggest a combination of avoidance and intoxication. Sprague (1964b) found that the lowest metal concentration causing a migrating salmon to show an avoidance response in soft water was 0.002 mg/liter copper (as copper sulfate) or 0.005 mg/liter zinc (as zinc sulfate). Avoidance by fish also occurred at a mixture of 0.0004 mg/liter copper and 0.006 mg/liter zinc. These concentrations are well below those found to be acutely toxic to fish and illustrate how sensitive salmonids are to heavy metal pollution. Fish would certainly avoid the copper and zinc concentrations found in the upper Panther Creek drainage.

FINGERLING TROUT SURVIVAL

In 1972 rainbow trout fingerlings confined in "live" boxes at sites on Panther Creek upstream and downstream from the confluence with Blackbird Creek, showed highly significant differences in survival. The line between excellent and poor fingerling survival was the point where Blackbird Creek enters Panther Creek. Fish placed in Panther Creek upstream (station 10P) from any input of acid mine water had only a 2 percent mortality rate, but the mortality rate of those fish below the confluence of Blackbird and Panther Creeks ranged from 86 percent at station 11P to 48 percent at station 3P, located farther downstream from the entrance of Blackbird Creek.

In 1975, Kent Ball[2] used live box tests to evaluate the effects of stream channelization work on Blackbird Creek by the Salmon National Forest. He found that channelization increased mortality of juvenile steelhead trout in Panther Creek. In a follow-up study in 1976, percent mortality was still higher than prechannalization rates.

Studies by the Idaho Bureau of Mines and Geology show an increase in the concentration of heavy metals in mine drainage water during high flows (Baldwin and others 1978). Such flows correspond to the time when juvenile salmon and steelhead trout would normally be migrating in the Panther Creek drainage. In April 1977, Ball set live boxes in Panther Creek in an atempt to assess fish mortality during the migration period. After 5 days, he found that fish mortality was 100 percent below Blackbird Creek and 20 percent below Big Deer Creek.

[2]Ball, Kent. 1978. Panther Creek fish status report. Idaho Dept. Fish and Game.

EFFECTS OF HEAVY METALS ON FISH

Dissolved heavy metals, commonly found in waters polluted by industrial mining operations, are toxic to the aquatic biota (Cairns and Scheier 1957; Lloyd 1960, 1961a, 1961b; Lloyd and Herbert 1962; Mount and Stephen 1967; Tarzwell and Henderson 1960). However, it is difficult to determine the actual metal concentration toxic to fish.

Toxicity depends on fish species, age, and stage of development (Lloyd 1960), water temperature (Chapman 1973), pH, dissolved oxygen concentration, and total hardness. In general, fish mortality results from exposure to high concentrations of a metal, and continuous low levels of a metal produce chronic effects, such as behavioral changes, reproductive failure, or fry mortality (Chapman 1973). Both ultimately affect the survival of a species in a stream.

Doudoroff and Katz (1953) reviewed nine research studies on the effects of heavy metal ions in water. They reported that the studies attributed death of fish in waters containing dissolved heavy metals to coagulation or precipitation of mucus secreted by the gills or to direct damage to gill tissue. Skidmore and Tovell (1972) found that the specific toxic action of zinc was to the epithelial tissue of the gills.

The virtual disappearance of fish in the Panther Creek drainage is probably the result of acute toxicity as well as of long-term effects of chronic heavy metal toxicity. Drummond and others (1973) found behavioral changes in brook trout at concentrations as low as 0.005 mg/liter copper. Studies on brook trout by McKim and Benoit (1971) showed that copper concentrations of 0.002 to 0.03 mg/liter had no effect on adult fish, but a marked effect on survival and growth of alevins and juveniles. Zinc concentrations of 0.18 mg/liter were found by Brungs (1969) to greatly reduce egg production of the fathead minnow (*Pimephales promelas* Rafinesque), a fish more resistant to heavy metal toxicity than the salmonids. In the same study, Brungs found that fathead minnow growth was inhibited and mortalities occurred at 2.8 mg/liter zinc. Holcombe and others (1976) found that long-term exposure of brook trout to lead resulted in physiological changes. In three generations of fish exposed to lead concentrations ranging from 0.001 to 0.5 mg/liter, second and third generation trout developed spinal deformities (scoliosis). In additon, growth of third generation trout was reduced.

High concentrations of heavy metals in a stream result in very toxic conditions, in behavioral changes, in avoidance, and in long-term chronic toxicity to fish. Any or all of these factors could be responsible for the reduction or elimination of fish populations from the Panther Creek drainage.

CONCLUSIONS

Results of studies discussed here suggest that past mining activities in the Blackbird mining district have caused extensive pollution of the Panther Creek drainage. Sediment and dissolved heavy metals from mining and milling operations have virtually eliminated the aquatic biota, including anadromous salmon and steelhead trout in affected areas.

Heavy metals present in toxic concentrations are cobalt, copper, iron, manganese, zinc, and possibly lead. Not only are these elements toxic at the concentrations found, but synergistic toxic reactions can occur. The mine waters also contribute mineral acidity that decreases the pH in drainage streams, another factor detrimental to aquatic life. In addition, lowered pH levels result in increased solubilities of heavy metals in the water.

Heavy sediment loads and deposition downstream result from the erosion of waste dumps, tailings piles, and stream scouring during periods of high runoff. Such pollution will continue in the affected areas until extensive reclamation is done in the mine area.

These data can be used as baseline information to evaluate the effects of future mining or reclamation activity. The information presented here should alert the land manager to potential pollution problems that can result from mining activities. In addition, data reported demonstrate the need to rehabilitate areas disturbed by mining.

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Discusses studies made from 1967 through 1977 that show seepage from the no longer operating Blackbird Mine in east central Idaho has resulted in acidic waters high in sediment and heavy metals. Suggests high concentrations of cobalt, copper, iron, manganese, lead, and zinc in the Panther Creek drainage are the probable cause of diminished insect and fish populations in the area. Contends that pollution from the mined area will remain a problem in the drainage until rehabilitative measures are taken.

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

- Billings, Montana
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Mining and Reclamation in the West

U.S.D.A. FOREST SERVICE
GENERAL TECHNICAL REPORT INT-68
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EXPERIMENT STATION
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

RESEARCH SUMMARY

The soils scientist working on mined land must be aware of potential impacts of mining, as well as reclamation techniques available to him. This guide covers major points of concern to the soils scientist involved in planning for reclamation of mined land including: exploration and baseline data; soils and overburden analysis and sampling techniques; selecting storage areas; materials handling; spoils analysis; treating spoils problems; spoils surfacing; and monitoring and retreatment.

Information is presented in a question/rule/discussion format, and includes supporting graphic material, notes on additional sources of information, a glossary, and an index.

ACKNOWLEDGMENTS

The contents of this guide are based on presentations and discussions during the Surface Environment and Mining (SEAM) sponsored Soils Workshop, March 7-9, 1979, Denver, Colorado. Credit is due all attendees and presenters for their input. Those who attended are listed in appendix B. In addition, major contributors are listed under chapter titles as appropriate

A special note of thanks is extended to Earl F. Aldon, Ardell J. Bjugstad, Paul E. Packer, and Robert Partido, members of the cadre which planned the workshop. The workshop program coordinator was Edwin R. Browning (SEAM) and the technical adviser was Grant Davis (SEAM).

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USER GUIDE TO SOILS

MINING AND RECLAMATION IN THE WEST

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INTRODUCTION

IERAL AND NONMINERAL RESOURCES

n adequate, reliable supply of minerals is ntial to the economy and security of the ed States, since minerals provide the physi- basis for almost all activities of U.S. citizens. e imports can satisfy an important part of country's minerals demand, they make the vulnerable to the economic and political sions of foreign countries. Thus, the mineral sits within the U.S. are a most important ce of this nation's supply.

substantial portion of the domestic min- supply presently comes from lands man- by the Federal Government. Federal lands known to contain a majority of the metallic rals, as well as major resources of coal, oil , geothermal steam, uranium, and oil and These same Federal lands, however, also ain valuable nonmineral resources, including er, forage, water, wildlife, scenic landforms, wilderness. The Government's holdings of resources are now among the most signifi- in the world.

hile it is clearly in the national interest to ide for the identification and production of mineral resources on Federal land, it is also ssary to provide for a sustained high-level put of the various renewable resources on land. Thus, the demand for mineral develop- t must be balanced against the demand for wable resources and the land-management cy's responsibility to reasonably protect environment affected by mineral-related ations.

NERALS IN THE LAND-MANAGEMENT PLANNING PROCESS

he Forest Service, as one of the agencies onsible for Federal land management, has a ively sophisticated planning program for the management of nonmineral resources on land under its jurisdiction. Historically, however, the Forest Service's land-management and planning systems have treated minerals as a distinct category outside of the mainstream of the land-management planning process. There are two basic reasons for this separation:

1. The mining and mineral leasing laws have tended to make mineral activity the preferred use on any Federal land open to such activity. The thinking has been that on lands open to mineral activity, mineral development will generally override the designated primary non-mineral uses.

2. Planning for use of the mineral and non-mineral resources is complicated considerably by the difficulties of identifying and estimating the value of mineral resources. Mineral resources can be found only through costly and risky exploration. Therefore, land-management planning has tended to concentrate, at least until a mineral discovery is made, on the surface resource potential of the land.

The long-standing premise that mineral activity is always the most valuable use of a tract of land is increasingly being challenged. Many mineral deposits being discovered today are of lower grade, located at greater depths, and are therefore more expensive to find and mine than the high-grade surface deposits formerly developed. Another significant factor is that nonmineral surface resources are now also considered to be scarce, and their value has increased accordingly.

Hence, when all the mineral and nonmineral values are weighed for a particular proposal at a specific location, the value of the mineral resources may be outweighed by the value of the nonmineral resources. The process of weighing values usually occurs in an Environmental Assessment required by the National Environmental Policy Act of 1969 (NEPA) (P.L. 91-190) and is basic to determining the proper mix of uses for any given land area.

Given this situation of mineral and nonmineral values on the same tract of Federal land, decisions as to the proper use of a particular tract of land will always involve balancing the values of mineral and nonmineral resources. If this balancing is to be done in a reasonable manner, adequate information and analysis of all values are needed.

BACKGROUND: THE FORMATION AND MISSION OF SEAM

Realizing the complexity of such decisions, in 1973, the Forest Service chartered the Surface Environment and Mining program (SEAM) to coordinate research, development, and application related to land impacts resulting from minerals exploration and development in the West. From 1973 to 1979, SEAM sponsored more than 150 research and development projects. Together, the projects have greatly added to the body of knowledge surrounding the management of land in mineralized areas. (For purposes of this discussion, mineralized areas are defined as those areas that have some potential for mining.)

To get this knowledge to the specialists in the field in a form they could readily use, SEAM brought together researchers and users from industry, Federal agencies, and the academic community to share their practical knowledge and study results in a series of workshops. The information presented at these workshops is organized into five user guides. Each guide focuses on a specific discipline involved in managing surface resources that may be affected by mineral activities and is written for specialists in these disciplines. The guides will also be of use to land managers, land planners, and other specialists, since many activities related to minerals-area management demand that a variety of skills be applied to achieve an integrated approach.

In addition to the User Guide to Soils, guides have been written for vegetation, hydrology, engineering, and sociology and economics. Cross-referencing among these guides is provided in the index. A handbook for minerals specialists has also been written. A handbook for land managers will provide a general overview of administrative considerations surrounding mineral commodities commonly explored fo[r] developed on national forest lands adminis[tered] by the Forest Service. Concurrent wit[h] development of the SEAM user guides, a [U] handbook of visual management relate[d] mining and reclamation, entitled "Mining,'[...] press as volume 2 of the National Forest [L...] scape Management Series. A guide for the [...] life specialty is also planned. All guides w[...] updated periodically to keep them current [...] research findings.

The purpose of the guides is to help spec[...] more clearly understand their role in m[...] exploration and development activities by [...] lining some of the major considerations [...] must address to insure that such activities [...] grate with land-management plans; that im[...] are mitigated to a reasonable degree; and [...] reclamation meets state-of-the-art perform[...] standards. Perhaps by using these guides [...] common starting point, those involved in [...] erals management can more easily work tog[...] toward achieving these common goals: (1) a[...] priate consideration of minerals values in [...] management planning; (2) protection of su[...] resources during mining activities; and (3[...] lamation of surface-mined land to a produ[...] use.

HOW TO USE THIS GUIDE

The chapters of this guide cover topics [...] concern the soils scientist during both [...] management planning and any subsequent [...] erals activity. Within each chapter, major [...] will be addressed in this way:

- Considerations: These are the questio[...] soils scientist should ask about each topic.
- Rules: These general statements answe[...] questions and direct the soils scientist t[...] the type of site-specific information the [...] manager may need to make decisions. Rul[...] set in italic type.
- Discussions: The discussions explai[...] reasoning behind the rules and in some [...] give specific examples of how the rule[...] applied.
- Exceptions: Exceptions to various [...] ments are given where applicable.
- Additional Information: Here the reade[...]

d basic references to further information on topic discussed.

The aim of this format is to help define the e of the soils scientist in minerals management. The guide is not intended to be a "cookok" on rehabilitation techniques. Rather, it is nded to set up a logical thought process ed on a question/answer approach. Such an roach allows for flexibility, eliminates unnecsry data gathering, helps simplify technical isionmaking, and allows for a systematic umentation of the decisionmaking process. hope that this organization of material will ke the guides equally useful to users in indus- Federal and State agencies, and the acanic community.

The role of the Forest Service staff is illused in table 1, "Stages of Mineral Exploration Development Activities," and table 2, les of Forest Service Specialists in Minerals ivities," which follow this introduction. As will note, the Forest Service soils scientist advise, review, and monitor. For example, ough materials handling takes place during ing and reclamation, the soils scientist will ew these plans when the operating plan is mitted prior to development and, if neces, suggest revisions to the plan to improve amation potentials. Then, during mining reclamation, the Forest Service specialist monitor these activities according to the roved operating plan. In this way, the effects the development will be managed in a prove, rather than reactive mode. In other ds, rather than reacting to crises, the soils ntist will be part of the forest's interdisciary (ID) team from the time land-managet planning begins. Then, if and when mineral vities occur, the team will have foreseen ential problems and will have determined eral rehabilitation objectives in advance.

oth land-management planning, in its broad application, and site-specific operational nning for mineral activities on National est System lands require the full range of interdisciplinary efforts so that information on both the mineral and nonmineral values can be presented to the decisionmaker in an integrated manner. The interdisciplinary approach to planning is uniquely suited to giving the best available assessment of the spectrum of opportunities and problems of managing surface resources that may be affected by mineral-related operations and the requirements needed for reasonable protection of nonmineral resources. Soils, vegetation, hydrology, topography, geology, wildlife, climate, and social and economic information are some of the factors that must be considered by the ID team.

Land management and planning must always proceed on the basis of existing information. In the case of mineral resources, this will almost always be difficult because the mineral resources are hidden beneath the surface, and information is provided in increments as exploration proceeds. One of the principal goals of Federal land management, therefore, should be to improve such management by obtaining better mineral-resource information and integrating it into the decisionmaking processes.

When using this guide, the reader should keep in mind that, for the most part, the information is concerned with scientific considerations. While other factors, particularly cost and legal constraints, are a crucial part of the planning process, discussion of these aspects is limited here.

One final note: Successful rehabilitation is as much an art as a science. To clarify specific points or to keep up with new developments, readers are urged to contact the researchers who contributed to this guide or their regional reclamation specialists.

Additional Information:

For more information on the mining process, refer to "Anatomy of a Mine," USDA For. Serv. Gen. Tech. Rep. INT-35. 1977. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Table 1. — *Stages of mineral exploration and development activities*[1]

Prospecting	Exploration	Feasibility studies/operating plan
A. Administrative Action No administrative action required; however, some evidence of mineralization or a hunch	A. Administrative Action Permit/Lease Notice of intent from miner (for certain commodities, may also serve as operating plan if there is minimal surface disturbance) Exploration license EA may be necessary See Handbook for Land Managers (in press) for variation within commodities	A. Administrative Action Submission of necessary permits (E etc.) and operating plan—see Han for Land Managers (in press) for within commodities
B. Activities Literature search Geological inference Evaluation of existing data Research on rights to land/minerals	B. Activities More intensive literature search Access road construction On-site testing and evaluation of data—geological, geochemical, geophysical, drilling, sampling, shaft sinking Seismic activity Acquiring land/mineral rights Rehabilitation of exploration impacts Environmental and socioeconomic studies	B. Activities Feasibility studies Grade and size of deposit Cost of mining and rehabilitatior Market Fiscal Technical studies—mine design Environmental and socioeconomic (if not done during exploration) Decision to proceed with developm Preparation of operating plan inclu rehabilitation program and end u Ordering of equipment
C. Environmental Impacts Minimal, if any	C. Environmental Impacts Roads Drill holes Drill pads Dozer holes Exploration camps	C. Environmental Impacts Generally none at this stage
D. Tasks for the Soils Scientist None at this point	D. Tasks for the Soils Scientist Review of plans to reclaim land impacted by exploration Review and assist in soils aspects of environmental studies Review soils inventory progress in the mineralized area; if needed, recommend timely completion or upgrading	D. Tasks for the Soils Scientist Review adequacy of operating plan Reclamation Program — soils surveys storage area selection materials handling plans spoils analysis plan spoils surfacing and erosion contr Monitoring/retreatment program f Soils aspects of end use

[1] The various phases have considerable overlap. The material provided for each phase is illustrative, not complete, and co variation is found by commodity. The existence of a forest plan is assumed. Tasks (D) are primarily input from a land-ma agency's soils scientist. For purposes of discussion, the terms reclamation and rehabilitation are used interchangeably, a includes oil and gas activities.

elopment[2]	Mining/reclamation	Postmining
A. **Administrative Action** Approval of necessary operating plan	A. **Administrative Action** No administrative action required. Mining overlaps with development and reclamation overlaps with mining; reclamation of previously mined areas occurs concurrently with new mining as stipulated in operating plan Any changes in operating plan	A. **Administrative Action** Release of reclamation bond
B. **Activities** Securing of financing More extensive testing and definition of the mineral Construction of transportation routes and utilities Construction of mine and processing plant (facilities, water supply, etc.) Construction of waste deposits Continued evaluation of data Change mining plan if necessary	B. **Activities** Extraction of mineral Processing of mineral Depositing wastes Operation of transportation systems Rehabilitation Monitoring for any changes in biological and physical environment Amend mining and rehabilitation plan if necessary	B. **Activities** Surface owner manages land after bond release Monitoring for any changes in biological and physical environment Management and maintenance for end-use objective
C. **Environmental Impacts** Mine Processing plant Waste dumps Transportation and access routes Utilities Increased population resulting from construction	C. **Environmental Impacts** Impacts directly related to operational aspects of mining; impacts are strongly affected by commodity mined and type of operation	C. **Environmental Impacts** Directly related to management and maintenance activities
D. **Tasks for the Soils Scientist** Monitor impacts on soils Monitor soils related activities for conformance to operating plan. Advise on plan revisions when necessary	D. **Tasks for the Soils Scientist** Monitor soils impacts and activities for conformance to operating plan. Advise on plan revisions when necessary Advise from a soils standpoint on release of reclamation bond	D. **Tasks for the Soils Scientist** Monitor any continued impacts on soils Manage soils for end-use objective

[2] Development is herein defined as the phase which begins after the right to mine has been established.

Table 2.—*Roles of Forest Service specialists in minerals activities*

	Prospecting	Exploration	Feasibility studies/operating plan
Vegetation specialist	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in vegetation aspects of environmental studies	Review adequacy of operating plan fo Reclamation program — species selection plant materials site preparation planting methods cultural treatments Monitoring/retreatment program for vegetation Vegetation aspects of end use
Soils scientist	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in soils aspects of environmental studies Review soils inventory progress in the the mineralized areas; if needed, recommend timely completion or upgrading	Review adequacy of operating plan fo Reclamation Program— soils surveys storage area selection materials handling plans spoils analysis plan spoils treatments spoils surfacing and erosion control Monitoring/retreatment program for s Soils aspects of end use
Hydrologist	Establish baseline water-quality monitoring as needed according to plan	Review of plans to reclaim land impacted by exploration Review and assist in hydrologic aspects of environmental studies	Review adequacy of operating plan for Hydrologic considerations— surface water subsurface water snow management roads impoundments mine drainage Hydrologic aspects of end use
Engineer	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in engineering aspects of environmental studies	Review adequacy of operating plan for Engineering considerations— air pollution transportation facilities surface-mine facilities mine-waste disposal embankments tailings dams and impoundments subsidence Engineering aspects of end use
Economist	Monitor factors which affect supply and demand for minerals Make forecasts of supply and demand Predict probability	Analyze costs and benefits of alternative exploration methods Participate with the sociologist in identification of existing and emerging issues	Provide expertise in environmental ana process: issue identification decision criteria cost/benefit analysis of alternatives tradeoff and opportunity-cost evalu Analyze effects of development on: demand for surface resources human behavioral patterns community economics
Sociologist	Identify the basic social/cultural descriptors of the affected communities Note current trends	Assist in structuring public involvement plan for appropriate: issue identification issue analysis mitigation action Identify critical trigger points from a social perspective	Provide expertise in environmental ana process: decision criteria issue identification Analyze effects of development on the cultural and political community Consider effects of alternative plans on social well-being

Development	Mining/reclamation	Postmining
Monitor vegetation impacts and activities for conformance to operating plan. Advise on plan revisions when necessary	Monitor vegetation impacts and activities for conformance to operating plan. Advise on plan revisions when necessary Advise from a vegetation standpoint on release of reclamation bond	Monitor any continued impacts on vegetation Manage vegetation for end-use objective
Monitor impacts on soils Monitor soils-related activites for conformance to operating plan. Advise on plan revisions when necessary	Monitor soils impacts and activities for conformance to operating plan. Advise on plan revisions when necessary Advise from a soils standpoint on release of reclamation bond	Monitor any continued impacts on soils Manage soils for end-use objective
Monitor impacts on hydrology	Monitor impacts on hydrology and hydrologic aspects of rehabilitation program Have hydrologic input into release of reclamation bond	Monitor any continued impacts on hydrology Manage hydrology for end-use objective
Monitor engineering-related activities for conformance to operating plan Advise on plan revisions when necessary	Advise from an engineering standpoint on release of reclamation bond	Monitor any continued impacts from engineered structures Manage structures for end-use objective
Record costs Monitor economic changes	Record costs Monitor economic changes	Monitor to determine accuracy of predictions for future use
Monitor Record changes Identify areas of individual or group stress relating to mineral activity and make recommendations to mitigate effects	Monitor Record changes	Monitor and record critical changes to establish new baseline situation

Chapter 1
EXPLORATION AND BASELINE DATA

pter Organizer: Grant Davis

or Contributor: Grant Davis

lineral exploration is the process of identi-g and investigating "targets" in order to dis-er an economic mineral deposit. Exploration ns with regional studies that create little or disturbance or occupation of the land. In ition to compiling existing geologic and togeologic information, exploration also in-es geologic mapping and geochemical sur-s. By the time a regional study has defined ific target areas, only a small portion of the ls originally considered is selected for more nsive study and exploratory work. At this e, some land disturbance—drilling, for exam-—may occur.

hould a mineral deposit be found, the area and involved is subject to more intensive ex-atory work in a tighter pattern and is accom-ied by more surface disturbance. If the ex-atory work locates an ore body, develop-t and mining are confined to an even more lized land area. Thus, a mining company's sion to explore an area for mineral deposits require the land-management agency's per-nel to become involved in a more intense ysis of the site than would normally occur ng land-management planning.

t input is needed from the soils scientist ng exploration?

uring exploration, the activities of the soils ntist will increase in intensity in direct pro-ion to the types and magnitude of surface urbances caused by the various phases of ex-ation. And, if an exploration permit is ed, the soils scientist should be among the n reviewing exploration plans.

ussion:

uring the initial and intermediate stages of exploration, when seismic activity, some core drilling, and pioneer road building may occur, the soils scientist can generally rely on existing soils survey data or extrapolate soils data from areas with similar environments in order to advise on the potential for rehabilitation of these disturbances. If, however, access to the site will cause significant surface impact, an Order 3 soils survey may be needed. Based on this knowledge, the soils scientist should be prepared to offer information on alternative road sites if the soil at the site selected by the operator is either unstable or so productive that it should not be disturbed. Consult with an engineer on these decisions.

Any pad construction will also require a site-specific study in order to determine how it can be reclaimed. If exploration leads to excavation of waste rock material, the soils scientist should offer his expertise along with the engineer to insure that salvageable soils and the waste materials are stockpiled properly and positioned to best advantage on the rehabilitated spoils pile.

During this time, the soils scientist should also work with the mining operator to gather preliminary information on the geology and overburden of the area. For example, if possible, he should obtain the drill cores or a log of the core drilling activity. If the company is not taking core drills, even chips will be valuable in this preliminary analysis, provided samples collected can be related to depth of drilling.

Obviously, as is the case during land-management planning, this information will remain rather general, but it will provide some indication of potential problems, such as toxicity or erodibility, that may be encountered if the site is mined.

Does the Forest Service have access to a mining company's data?

If a mining company has collected data about a leasable mineral, the company is required to

give the Forest Service certain information about such mineral deposits. A prospecting permit may require the company to supply this information. A coal license absolutely requires this information from a mining company. For locatable minerals, any information collected is considered "privileged," and the company that collected it controls access to it.

Discussion:

Because mining companies have complete control of certain information they collect during exploration, prior data collection by the Forest Service ID team is essential. The Forest Service should have information about every mine site on its land, whether for a leasable or locatable mineral, because, in either case, it will be the responsibility of the Forest Service to insure that surface conditions are not irrevocably harmed during mining. In addition, a close working relationship between the Forest Service and the mining company, developed early in the mining process, can be beneficial to both parties since their combined effort can produce a more thorough data base.

BASELINE DATA AND THE MINING PLAN

Once exploration is complete and the mining company determines that it will mine the site, an Environmental Assessment may be in order and the formal gathering of baseline data to be included in the mining plan begins. Baseline data measure the conditions existing on the site prior to disturbance, help determine reclamation goals, and provide a basis against which reclamation success can be measured. Based on these comparisons, the mining operator may or may not be released from his bond of liability subsequent to mining and reclamation activities.

At this point, more detailed information about the site may be needed to answer specific issues or management concerns identified in the planning process. This information must be scientifically sound and well documented. In addition, ID team members should coordinate their efforts so that the data collected do not overlap.

What is the role of the soils scientist in baseline data collection and approval of the mining plan?

The soils scientist will advise on the type and extent of soils information that will be req from the operator in order to approv mining plan. He will be specifically conc with data needed to answer questions relat soils in the Environmental Assessment. The To collect sufficient information in order t dict (1) the characteristics and volume o vageable soil materials; (2) what type of material will result from mining; and (3 rehabilitation potential of the site.

Discussion:

The soils scientist should determine wha information is appropriate to the concern need to be answered, what funds are ava for collecting the data, and who will coll He should require only the level of data n to answer specific questions for the land ager or to meet legal requirements. This of data usually requires on-site studies.

Soil types must be indicated in the m plan, which will require at least an Or soils survey for the general area and pro an Order 2 or 1 survey on areas planned disturbed. At this point, productivity r will be developed by soil correlation techr based upon the documented history and agement experience with the same or s types of soils series as the one under s Greenhouse studies and lab analyses will ge ly be required in order to identify tox infertile soils materials and to predict we ing characteristics, erosion potentials, moisture factors. The core samples coll during advanced exploration work can be for this analysis.

After analysis of these data, the soils sci should be able to advise the land m whether to accept, reject, or modify a pany's mining plan, based on how the addresses soils considerations. The soils sci may also be responsible for proposing opti the mining plan either alone or as a mem an ID team. The land manager can req periodic review of the plan during which c can be made if (1) the mining processes a reasonably damaging soils resources; or (2 preliminary baseline data are included i mining plan.

Additional Information:

Detailed soils and overburden analysis,

done only after the company has determined will mine the site but prior to approval of the ning plan, is discussed in chapter 2.

o collects baseline soils data?

Either the Forest Service or the mining comy may collect the baseline data. Responsiity for data collection will be negotiated ween the Forest Service and the mining npany in each mining situation after the npany has made the decision to mine.

cussion:

When the mining operation will be on Forest vice land, it is the responsibility of the land nager to determine if the mining plan has an quate baseline data design, and then if the a are collected according to the plan.

Although it is the responsibility of the Forest vice to insure that baseline data requirements met by operators on Forest Service land, certain areas of the country, the Forest vice is considering allowing State agencies to force their own State requirements on tional Forest System lands because these ulations are at least as stringent as Forest vice or Federal requirements. An example is State of Wyoming. In these situations, the rest Service will still approve mining plans d will retain authority over Forest Service ds.

In the case of small mine operators, exteni data collection may be economically unfeale. To aid these operators, Federal assistance be applied for through the Small Operators istance Program, Office of Surface Mining, S. Dept. of the Interior. This program was ablished by the Surface Mining and Reclamain Act of 1977 (P.L. 95-87, 30 U.S.C., Secs. 1)1 etseq.).

o must gather the soils information for vironmental Assessments if they are required?

If the operation is located on national forest ds, the forest supervisor may be required to vide the information, in which case the soils ntist will probably be involved in data lection.

cussion:

The Forest Service soils scientist may be acly involved in data collection, or involved only in review of the data, depending on who must supply the data. In either case, the same kind of information is needed.

Should baseline data be computerized?

If a large amount of data will be collected or an Environmental Assessment or Environmental Impact Statement is required, computerizing the data may aid in easy retrieval during mining activity and postmining monitoring.

Discussion:

The decision to computerize the data should be made before or in the early stages of the data collection process. If there is going to be a large baseline requirement and an intense monitoring requirement throughout the mining process, the option to computerize the data should be considered.

What other activities are important considerations during baseline studies?

The soils scientist should urge those doing baseline studies to watch for archaeological resources as the site is examined. The specialist should also encourage establishment of permanent study plots for use throughout the mining, reclamation, and postmining phases.

Discussion:

Although a trained archaeologist will conduct an official paleontological or archaeological survey, all members of the team should aid in locating such objects during field studies.

Study plots will be essential throughout the mining process to determine what reclamation techniques are most successful on the site (fig. 1).

Additional Information:

For more information on baseline studies, refer to:

"A Systems Approach to Ecological Baseline Studies," U.S. Dept. of the Interior, Biological Services Program, Fish and Wildlife Service, FWS/OBS-78/21. March 1978.

"Procedures Recommended for Overburden and Hydrologic Studies on Surface Mines," by James Barrett, Paul Deutsch, Frank G. Etheridge, William T. Franklin, Robert D. Heil, David B. McWhorter, Daniel Youngberg.

Colorado State University and USDA For. Serv., Douglas, Wyo. December 1978.

"Guidelines for Estimating Potential Land Capability and Range Sites as a Part of Reclamation Planning and Alternative Anal[illegible]," Thunder Basin National Grasslands, Hayd[illegible] D. Rounsaville, USDA For. Serv., Medicine [illegible] National Forest (location). September 1977.

Figure 1. On-site study plots are valuable in testing proposed revegetation techniques.

Chapter 2
SOILS AND OVERBURDEN ANALYSIS AND SAMPLING TECHNIQUES

apter Organizer: William A. Berg

ajor Contributors: William A. Berg, Stephen Merrill, Douglas J. Dollhopf

After a mining company has pinpointed the ineral deposit it plans to mine, a determination ust be made on the reclamation potential of e site. The baseline studies discussed in chapter 1 will aid the mine operator and the land manager in making such a determination. Soils and overburden analysis is a special component of these baseline studies, because these tests will identify if and how much topsoil should be stockpiled for placement on the mined spoils. (For purposes of this discussion, overburden includes materials overlying a minable deposit, up to but not including the topsoil. See figure 2.)

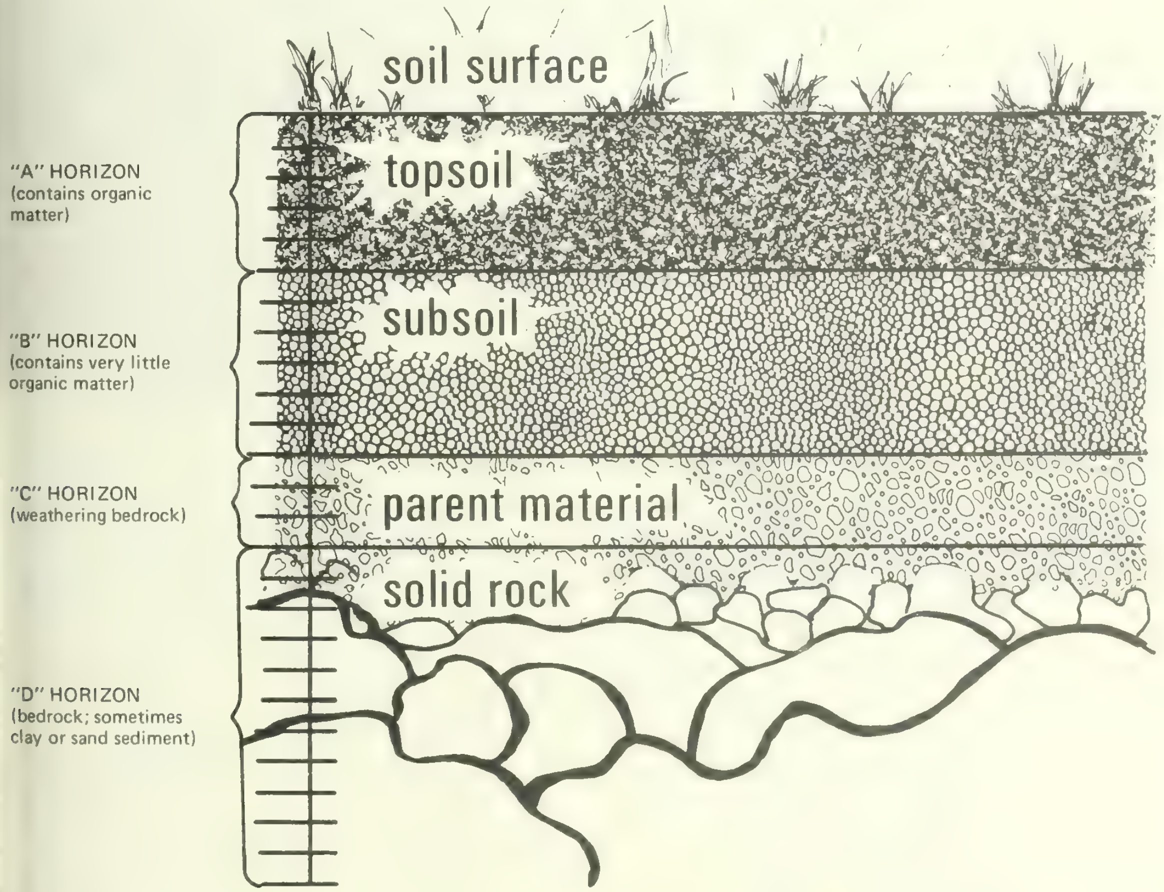


Figure 2. For purposes of discussion in this guide, soils compose the "A" horizon shown in the above profile. Overburden is the B, C, and D horizons, which overlie the mineral seam. (Utah State University)

Similarly, the analysis will identify zones in the soils or overburden that may adversely affect revegetation efforts when this material is replaced on the site as spoils.

Mining and reclamation plans are drawn up based on this premining analysis. For example, a decision can be made on how much topsoil to save. If feasible, the plan may state how selective handling of certain inhibitory zones will be accomplished—perhaps by burying and capping them—so that the most desirable material for plant growth is left on or near the surface. In addition, certain chemical and physical treatments of the spoils may be planned to ameliorate foreseen problems.

Caution in relying completely on these premining tests is important, however, because the actual spoils may exhibit characteristics different from those predicted during soils and overburden analysis. Thus, spoils analysis after mining and grading must always be done (see chapter 5), and the mining operator should be prepared to alter his rehabilitation plan if the results of spoils analysis indicate previously undetected problems.

Final interpretation of the analyses run during premining sampling must be made by the soils scientist in the field. He chooses the appropriate tests, sends them to the lab if necessary, looks at the results, and correlates these results with what he observes on the site.

This chapter will discuss the analyses recommended to characterize the physical and chemical properties of the soils and overburden; use of analyses to predict productivity and erodibility; analyses specifically recommended to determine if and how much topsoil should be stockpiled for respreading on the spoils; and sampling methods commonly used. Some of these analyses can be done by field observation; others must be performed in a lab. The analyses performed should be appropriate to the specific site, based on the knowledge the soils scientist has gained from soils inventories and other baseline studies. Obviously, not all tests described in this chapter will be necessary on any one site. Also note that this discussion is based on current research, but, in some situations, State or Federal regulations may prescribe the types of soils and overburden analysis that must be performed. In addition, other members of the ID team, for example, the engineer, may need other types of tests. The premining analysis program shoul coordinated with these other specialists.

ANALYSES TO CHARACTERIZE SOIL AND OVERBURDEN

How are the appropriate tests selected?

Because more than one test can be use identify the same characteristic, it is rec mended that the most basic tests be done f Then, if the characteristic under analysis sh up as questionable or a possible problem further tests should be run. This step-d approach to soils and overburden analysis save both time and money.

Discussion:

Tables 3 through 7 indicate various anal used to characterize soils and overburden. "S" following certain tests indicates that t should only be used in special situations. S of these situations are outlined in the follow discussion; the soils scientist can also mak determination on the necessity of these t based on the results of the basic analysis.

How is overburden information obtained?

Overburden information is obtained from horizon sampling during soil mapping, from cores taken from the site during explora drilling, or from materials excavated du exploration. Soil horizon sampling is gener confined to the upper 5 ft. If necessary, a tional cores may have to be drilled.

Discussion:

A major step in mined-land reclamation is mining overburden analysis. Thus, it is extre ly important that the mine operator be av that any samples taken to evaluate the deposit can also be used to determine the p erties of the overburden and the overburd reclamation potential. If core samples are ta during exploration, they should be saved for analysis. Due to their expense, however, t should only be run after the mining comp has determined it will mine the site, but prio submitting the operating plan.

What physical characteristics should be ide fied by field observation?

Physical characteristics important to soils

erburden analysis include horizon thickness, hology, coarse fragments, color, texture, ucture, consistency, hardness, root distribu-n, presence of lime, presence of soluble salts, d kinds of vegetation present.

scussion:

Much of the work involved in field observa-ns of physical characteristics is conducted as rt of the soil survey. Table 3 lists the field servations recommended to determine physi- characteristics in the soils and overburden. In ne cases, a characteristic important to the soil not applicable to the overburden and vice sa. Some specific notes on the tests listed in le 3 follow:

• Coarse fragments. It has been noted that rse fragment identification in the soil is often itted. But if the soil has 70, 60, even 40 per-t coarse fragments, lab tests will be inter-ted differently and thus these fragments uld be noted.

• Hardness. Hardness and accompanying lith-gy information indicate that the overburden terial is, for example, a hard shale or a soft le.

• Root distribution and vegetation. The soils scientist should work with the vegetation specialist in noting these characteristics.

Additional Information:

Most of the characteristics listed in table 3 can also be found on profile description forms, such as the Soil Conservation Service form SCS-232 or the Forest Service form FS 2500.

What physical characteristics should be identified by lab analysis?

Texture, dispersion, weatherability, water-retention capacity, saturation percentage, and hydraulic conductivity are all lab tests that may be performed to further define the physical characteristics of the soils and overburden.

Discussion:

Table 4 lists the lab tests recommended to characterize the soils and overburden. Some of these tests will be used by the engineer rather than by the soils scientist; however, they are included in the list because sampling can be done at the same time for both types. Other notes on specific tests:

• Texture of the soil (fig. 3 and 4). If the experienced soils scientist can make a determina-

Table 3.—*Field observations of physical characteristics*

Observe	Soil	Overburden
Horizon thickness	Yes	NA[1]
Lithology, including parent material	Yes	Yes
Coarse fragments	Yes	NA
Color	Yes	Yes
Texture	Yes	Yes
Structure	Yes	NA
Consistency	Yes	NA
Hardness	NA	Yes
Root distribution	Yes	NA
$CaCO_3$	Yes	Yes
Soluble salt/crystals	Yes	Yes
Vegetation (species composition and ground-cover characteristics)	Yes	NA

A: Not applicable.

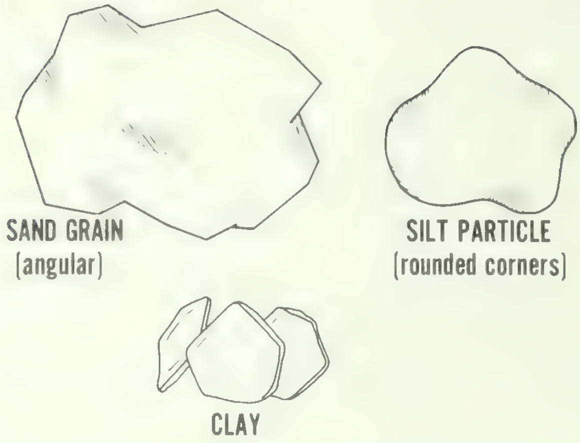


Figure 3. Texture is determined by the proportions of sand, silt, or clay contained in the soils and overburden. (Utah State University)

tion of soil texture in the field, laboratory ana-
sis may not be necessary. When extremes i
either clay or sand exist, however, texture te
should be made to obtain more information a
to verify field estimates.

• Dispersion. Dispersion is useful to indic
the initial slakability or weathering of sp
material, especially if the material is of a c
type.

• Weatherability. This test should be run
overburden materials if they will become
plant-growth medium after mining. In additi
it is useful to identify exposed rock strata a
note how they have weathered, then relate th
observations back to weatherability lab tests
the core samples.

• Water-retention capacity (fig. 5). In so
cases, if the soils scientist feels he has a go

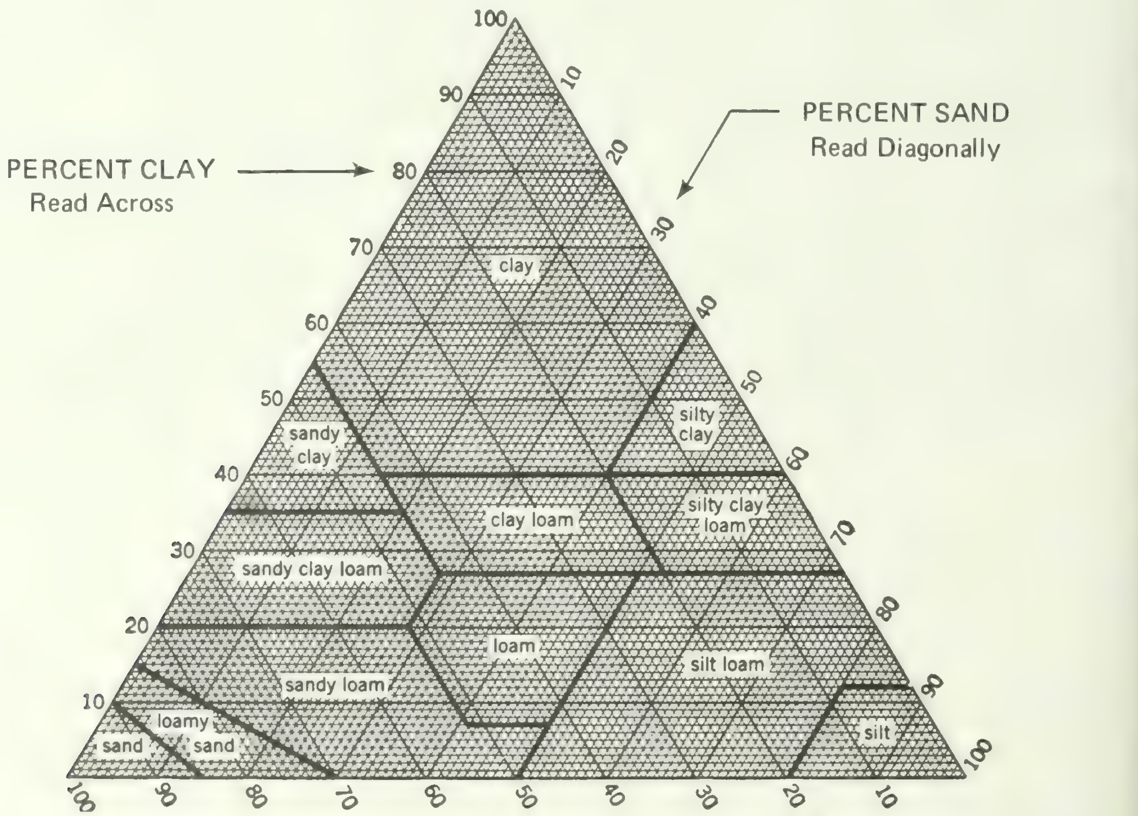


Figure 4. Soil texture triangle. (USDA Soil Conservation Service)

derstanding of the soil's texture and organic tter content through field observations, he y be able to adequately estimate water-ention capacity without running this specific t. In arid areas, however, such as the South-st and Great Basin, water-retention capacity, expressed by bar or tension values, is con-ered a critical interpretation. More about this t follows later in this chapter.

Saturation percentage. Saturation percent- is used as an indicator of sodium problems l thus is needed where high sodium is pected.

Hydraulic conductivity. This test adds to soils scientist's knowledge of the kind of /moisture relationships that may occur after ning. More about this test follows later in this pter.

Atterburg limits and COLE tests. Although se tests are used by engineers, the soils scien- should try to coordinate his own sampling testing schedule with the engineer. If the ineer or other members of the interdisciplin- team recommend additional tests, these uld be included in the same lab analysis tract.

at fertility analyses should be conducted?

nalyses of nitrogen, phosphorus, potassium, ain trace elements, presence of calcium, mag-ium, and sodium, and cation exchange capacity are commonly done on soils and over-burden to determine nutrient levels.

Discussion:

Table 5 outlines the types of fertility tests used. Refer to this table while reading the following descriptions.

Tests for nitrogen, phosphorus, and potassium are recommended on both soils and overburden to detect deficiencies. Especially in dry climates, knowledge of the natural fertility of the soils and overburden is important in making manage-

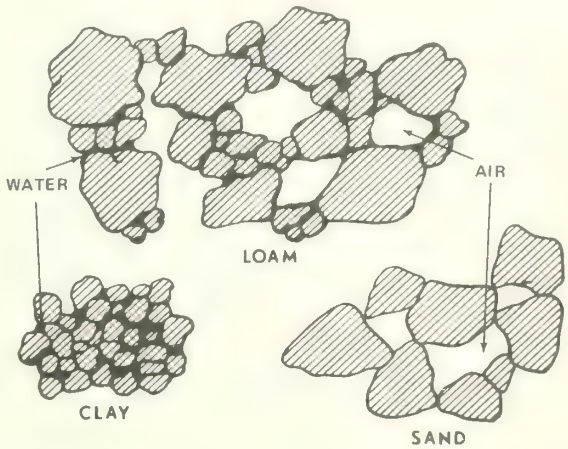


Figure 5. Clay has a greater water-retention capacity than loam; sand has less water-retention capacity than both loam and clay. (Utah State University)

Table 4.—*Laboratory analysis of physical characteristics*

Lab Test	Soil	Overburden
Texture	S[1]	Yes
Dispersion	No	S
Weatherability, slaking	No	S
Water-retention capacity (as measured by bars)	S	S
Saturation percentage	S	S
Hydraulic conductivity	S	S
Atterburg limits liquid limit plastic index	Consult Engineers	
COLE (Coefficient of linear expandability)	Consult Engineers	

[1] In special situations.

ment decisions for handling these materials. This is because there may be insufficient moisture to put the fertilizer into solution and make the nutrients available to the plants. In addition, some laws may require analysis of N, P, and K in the soils and overburden.

> **Exception:** It has been noted that because of the expense of selective handling of materials, it may be cheaper to apply the appropriate fertilizer after mining activity ceases rather than trying to separate out fertile zones in the overburden during mining.

Nitrogen tests—

• Mineralizable N is of particular interest when subsoils or geologic material may later be used as a plant-growth medium because it may indicate fertility problems undetected by overburden testing for organic matter or total N.

• It is very difficult to make N fertility interpretations from organic matter tests on the overburden.

Phosphorus tests—

• Plant-available phosphorus tests seem to work well for both soils and overburden.

• Sodium bicarbonate extraction is recommended for use as a phosphorus test on neutral and calcareous soils; the Bray No. 1 test is recommended on acid soils.

Trace elements—

• These tests should be run if the soils scientist thinks these elements may be deficient or present in toxic amounts; however, interpretations for most native species have yet to be worked out.

Lime, qualitative test—

• This acid test can be run to determine the presence of lime in the soils and overburden.

Cation exchange capacity—

• This test can be run if more information is needed about the cation exchange capacity of clays and organic matter in the soils and overburden.

What salinity-sodicity or acidity tests should be run?

Tests for salinity-sodicity include pH, soluble salts, water soluble ions, sodium adsorption ratio, exchangeable sodium percentage, water soluble anions, and gypsum. Acidity tests

Table 5.—*Soil fertility tests*

Test	Soil	Overburden
pH	Yes	Yes
Nitrogen		
Organic matter	Yes	Yes[2]
Total N	S[1]	S[2]
Soluble N	Yes	Yes
NH_4, NO_3		
Mineralizable N	S	S
Phosphorus		
Plant available	Yes	Yes
$NaHCO_3$ on neutral and calcareous soils		
Bray No. 1 on soils with pH less than 6		
Potassium		
Plant available	Yes	Yes
Iron, zinc, manganese, selenium, boron, copper (DTPA extractable)	S	S
Calcium, magnesium, sodium	S	S
Lime		
Acid test (qualitative)	Yes	Yes
Quantitative	S	S
Cation exchange capacity	S	S

[1]In special situations. [2]Interpretations difficult.

ude pH, qualitative and quantitative sulfides, d acid-base equilibrium. The initial test for ther alkaline or acidic soils or overburden ould always be pH. If soils or overburden ows a pH greater than 7, run tests for salinity-dicity; if the pH is less than 6, run tests for idity.

scussion:

See table 6 for tests recommended for salinity d acidity characterizations. Salinity problems ten occur in coal mining in the West. If the pH licates a salinity-sodicity problem, it is recom-nded that the sodium adsorption ratio and changeable sodium percentage tests be run gether to determine their relationship, rather an trying to infer exchangeable sodium per-ntage from sodium adsorption ratio. It ould also be noted, however, that the ex-angeable sodium percentage test is quite pensive.

• Water soluble anions. These tests help determine more about the relationship of water quality to soils and overburden.

• Gypsum. If gypsum is known to exist in the profile, problems foreseen from high sodium in the soils or overburden may be lessened.

• Acidity tests. These should be run if the pH value is below 6. Problems associated with acids occur particularly with sulfide minerals—the heavy metals of copper, zinc, gold, and silver. If an acid problem is indicated, qualitative and quantitative sulfide tests, acid-base equilibrium, and lime requirement will provide more information.

What toxicity analysis should be done?

Tests that indicate toxicity include emission spectrography and tests for trace elements such as boron, molybdenum, and selenium. An indirect test is pH. Radioactivity tests are advised in certain situations (see table 7).

Table 6. — *Salinity-sodicity and acidity tests*

Test	Soil	Overburden
Salinity-sodicity		
pH	Yes	Yes
Soluble salts EC on saturated paste	Yes	Yes
Water soluble Ca, Mg, Na, K	Yes	Yes
Sodium adsorption ratio	Yes	Yes
Exchangeable sodium percentage	S[1]	S
Water soluble anions CO_3, HCO_3, SO_4, Cl, NO_3	S	S
Gypsum	S	S
Acidity		
pH	Yes	Yes
Sulfide, qualitative	No	Yes
Acid-base equilibrium	No	S
Lime requirement	S	S

[1] In special situations.

Discussion:

One way to determine whether trace elements should be analyzed is to run an emission spectrograph on selected cores to pinpoint elements that may need further analysis. Then, laboratory tests for such trace elements as boron, molybdenum, and selenium can be run if necessary.

Some trace element analysis may also be required by law. The effects of all trace element concentrations are difficult to interpret, however, with the possible exception of molybdenum. For example, it is difficult to interpret tests for copper and iron, because if the soil is acidic enough to allow these elements to become toxic, the soil is probably already so toxic with soluble aluminum that plant growth is adversely affected. Thus, a low pH value can be used as a rough indication of soluble aluminum concentrations—and possible aluminum toxicity.

Radioactivity tests are indicated if material exhibiting uranium emissions will be used as a plant-growth medium or will have water running through it. Sedimentary material overlying uranium, and perhaps coal, may have this problem.

PRODUCTIVITY

How are the results of soils and overburden tests used?

These tests become the basis upon which the soils scientist predicts the productivity of the material as a plant-growing medium after mining. Both greenhouse tests and field observations can be used to verify test interpretations.

Discussion:

Productivity evaluations are made by correlating documented knowledge of established soil series to the experience gained in the actual performance of those or similar soil materials in the production of crops or native vegetation. Greenhouse and field studies are used to verify these evaluations on a site-specific basis and to check for possible changes in performance as a result of a disturbance or an expected disturbance.

Greenhouse studies of soils are useful because they may indicate soil characteristics not pinpointed by lab or field tests. Greenhouse studies are generally needed only in special situations, however, such as when the results of soils tests appear conflicting or when more information about differences among the same kinds of materials is needed. For example, if sandstone A produces 4 times as much vegetation as sandstone B in the greenhouse, then sandstone A is the better growth medium.

Greenhouse testing is done by taking soils samples from the site, putting them in a greenhouse, manipulating the samples so that the scientist can test various limiting factors, such as an N deficiency or pH, and then observing the soil's productivity under these conditions.

Greenhouse studies on overburden are particularly useful because, unless one can observe plant growth on a road cut or old disturbance, it is difficult to foresee how overburden will react as a plant-growth medium. The main disadvantage of greenhouse testing is that artificial temperatures and water controls in a greenhouse do not match natural conditions and thus soil

Table 7.—*Toxicity and radioactivity tests*

Test	Soil	Overburden
pH	Yes	Yes
Emission spectrography	S[1]	S
Boron (hot H_2O)	S	S
Molybdenum (NH_4-acetate)	S	S
Selenium (hot H_2O)	S	S
Radioactivity	S	S

[1]S: In special situations.

roductivity measurements in a greenhouse can e misleading.

Agronomic interpretations can be used to valuate greenhouse tests, although these interretations are sometimes difficult to relate to ative plant species.

Field studies are the most accurate way to iterpret soils laboratory tests. Field studies iclude setting up strips in the field and field bservations. For example, a site can be fertized with nitrogen in narrow strips to observe ie effect this fertilizer will have on plant owth in contrast to the nonstripped areas.

ERODIBILITY

Thus far, this discussion has focused essentially on more static characteristics of soils and verburden; however, various changes will take lace in reclaimed soils over a period of years nd decades. If the soils scientist can predict ome of these changes, he can make better ecisions on the quality and quantity of soils aterials to save and respread as topsoil.

Three important soil changes that will occur ver time include:

- Soil structure changes due to root action nd increased humus content.
- Erosional losses.
- Migrations of salt or toxic elements on some tes. (For information on salt or toxic-element igrations, see chapter 7.)

ow is erodibility predicted?

The universal soil loss equation can be used predict erosion due to water. The Soil Conservtion Service (SCS) wind erodibility groups can e used to predict wind erosion.

iscussion:

Factors important for evaluating water-eroon potential and a basis for developing erosionontrol management practices have been comined to form the universal soil loss equation:

A = R K L S C P

here:

A = computed soil loss expressed in tons/acre/ ear.

R = the rainfall factor, a measure of the erove force of specific rainfall.

K = the soil erodibility factor, a relative value, expressed from 0 to 1.0, which reflects the inherent water erodibility of a given soil.

LS = slope length and degree factors.

C = crop cover or management factor.

P = erosion control practice factor.

Numerical values for each of these factors have been set by the Soil Conservation Service (SCS). These values, however, are based on bare soils in a natural state. Currently the SCS is working on values for disturbed soils in the Western States.

K values are assigned based on the tendency of a soil to erode. In general, the K factor increases with silt in a soil and decreases with sand, clay, and organic matter. Based on this factor, recommendations on slope length and slope degree can be made. Or, if the soils scientist is faced with a steep slope problem, the K factor would help him determine what type of material might best be used on the surface of the slope to prevent erosion.

Because the K factors currently in use are for natural conditions, the soils scientist must realize that he is only getting a relative measurement when he uses these values to predict erodibility on a disturbed soil.

When evaluating wind erosion, the soils scientist can refer to the SCS wind erodibility soil groups. These can be used to predict what wind erosion hazards will be present if a certain material is put back on the surface after mining (see table 8).

Again, caution in relying on these predictions is necessary because recently disturbed soil, such as occurs after mining, may have a tendency to increase values over what will be found in SCS guides.

Another important erosion measurement is the "T value" or erosion tolerance level. This is the minimum expectable amount of soil that can be lost through erosion and still maintain the productivity level of the soil. The "T value" is the quality standard that management and mitigation are geared to.

K factors and wind erodibility groups must be analyzed in relation to the upper and lower limits of acceptable erosion established in the "T value." It should also be recognized that an acceptable erosion rate or loss in terms of soil productivity may not be within water-quality standards for sediment.

Table 9 can be used as a guide to determine

"T values" for soil material, considering the protection of both the investment of replaced soils and their productivity.

TESTS TO DETERMINE HOW MUCH SOIL MATERIAL TO STOCKPILE

Although most of the tests discussed in this section have been mentioned in the first part of the chapter, they are presented here in a slightly different form in order to call attention to the importance of deciding whether or not certain material should be saved from the site prior to mining, stockpiled, and then resurfaced on the site as topsoil after mining.

Questions considered by various reclamation laws and reclamation managers are: whether or not to save the topsoil and respread it; whether a "second lift" of subsoil materials should be saved; and how much material should be se[gre]gated and respread.

The reason the answer to the first questi[on]—whether or not to save and respread topsoi[l]—is usually "yes" is that unsurfaced spoils often [ex]hibit characteristics that are limiting or prohi[bi]tive to plant growth. These might include:

- Low infiltration rate, low water intake.
- Low water-conducting and water-reten[tion] capacity.
- Low fertility.
- Poor tilth (soil structure).
- Deleterious constituents, such as high [con]centrations of soluble salts or sulfides.

What tests determine surface-infiltration rate?

Indicators include shallow-infiltration [ra]te, percent dispersion, crust strength, texture, S[A]R, and percent organic matter.

Table 8.—*SCS wind erodibility potential of bare soils by soil groups*

Group	Soil Classes	Hazard
1	Sands	High[1]
2	Loamy sands	High
3	Sandy loams	Medium
4	Silty clays & clays	Medium
5	Loams, sandy clay	Slight
6	Silt loams, clay	Slight
7	Silty clay loams	Slight
8	Wet or stony	Slight

[1] Use Soil Conservation Service guides for specific values.

Table 9.—*Erosion tolerance limits related to thickness of replaced soil material (T values)*

Thickness of replaced soil material (inches)	Erosion tolerance limits (tons/acre/year)
40-60	4
20-40	3
10-20	2
less than 10	1

Discussion:

Percent-dispersion tests relate to surface sealing, are inexpensive, and thus are worthwhile tests to indicate surface-infiltration problems.

What tests determine water-intake and water-retention capacity?

Direct tests include deeper infiltration measurements, water-retention capacity, drainage, and unsaturated hydraulic conductivity. Indirect indicators are texture, SAR, and saturated hydraulic conductivity. The objectives of these tests: to determine how much water can be absorbed and retained by the spoil or overspread soils materials, and how fast water will move through spoils and soils.

Discussion:

Because, in many situations in the West, water supply is limited as a result of both climatic and soil factors, water-intake and retention capacities become important factors to consider when making resurfacing decisions. This is especially true when very coarse-textured spoils are involved.

At this time, there is no reasonably inexpensive, accurate and user-packaged test for unsaturated hydraulic conductivity that is suitable for reclamation decisions. Simple permeameter measurements, however, can be combined with water-retention data to get estimates of unsaturated hydraulic conductivity.

The drainage test is expensive; water-retention data are fairly inexpensive and are available on recent soil-series descriptions in soil surveys.

In addition to these tests, other information is necessary in order to make decisions on the soils' and spoils' predicted water-intake and water-retention capacities. For example, the soils scientist must have some knowledge of how much water the proposed plants will be able to use. This information can be obtained by observing water use on deeper, productive soils on areas near the proposed mining site. From this, the scientist will have a better idea of how much soil will be needed for resurfacing on the spoils.

What tests indicate fertility, tilth, and soil structure?

These tests have been discussed earlier in this chapter.

What tests are used to discover deleterious constituents?

Direct indicators are EC for salts, Ca/Mg ratio, and toxic-element tests.

Discussion:

If tests indicate that salts and toxic elements are not present, there is no problem. If the Ca/Mg ratio is too low, it can negatively influence plant growth.

How are the results of these tests, observations, and other data used to determine the quantity of material that should be stockpiled for later use as topsoil?

Some standards have been set by law. Where not dictated by law or where further information is necessary to make a decision on a particular site, two general sources should be pursued: (1) agronomic productivity data, species diversity, crop water-use data, and other ecological data on both productive and less productive, unmined soils in the immediate mining district; and (2) plot and "wedge" experiments with topsoil and/or subsoil materials spread over spoils. These experiments will yield both site-specific and general information on quantity questions.

Discussion:

"Wedge" experiments can validate assumptions reached in the analysis and evaluation of data. As an example of a "wedge" experiment to determine crop water-use and productivity on topsoil and subsoil, it was shown that where the underlying spoils exhibited a medium to high SAR and low hydraulic conductivity, placing 1 ft of soils over the spoils resulted in considerably less water use by various crop species than when 4 ft of soil materials were spread over the spoil. Of course, in some situations the ideal quantity of topsoil and subsoil may not be available. In these cases, physical and chemical treatments may be necessary to bring the spoils up to a quality that will support vegetation. For more on spoils analysis and treatments, see chapters 5 and 6.

An example of how data collected on a uranium mine site in Wyoming were analyzed to make surfacing and other reclamation decisions is shown in table 10. Table 11 provides general information on parameters to consider when

determining the suitability of soil material for salvage and resurfacing use.

SAMPLING METHODS

Proper sampling techniques are as crucial to adequate analysis of soils and overburden as are the selection of the tests that should be [illegible] Some research is being conducted on [illegible] gamma probes, electric logging systems, [illegible] seismic units to analyze overburden wit[illegible] relying solely on drilling and lab analysis. [illegible] rently, however, most testing relies on [illegible] drills. Techniques and frequencies of sam[illegible] vary widely, but the following are some ge[illegible]

Table 10. — *Guide for soil capability classification of reclaimed areas (prepared for a uranium mine on the national grasslands, Medicine Bow National Forest, Wyom[illegible])*

Capability class	Material suitability rating	Soil depth	Permeability of replaced material	Available water-retention capacity	Slope	Erosion tolerance limits	Climate: ETp 32°	Climate: PE	Index plants
		Inches	*Inches/hr*	*Inches*	*Percent*	*Tons/acre/yr*			
I	Good	Greater than 40	.2-6.3	Greater than 7.5 inches for 60 inch soil depth. Greater than 1.5 inch/ft	0-1	Greater than 4	Greater than 20	Greater than 44	Mature c[illegible] sorghum [illegible] those bel[illegible]
II	Good and fair	30-40	0.06-20.0	Greater than 5.0 inches for 60 inch soil depth. Greater than 1.0 inch/ft. Greater than 1.25 inch in surface ft	0-6	3	Greater than 14	Greater than 31	Corn or s[illegible] for silage [illegible] those bel[illegible]
III	Good and fair	20-30	Any	Greater than 3.75 inches for 60 inch soil depth. Greater than .75 inch/ft. Greater than 1.0 inch in surface ft	0-10	3	Greater than 10	Greater than 25	Small gra[illegible] grain and [illegible] crops
IV	Good and fair	10-20	Any	Greater than 2.0 inches for 60 inch soil depth. Greater than 0.4 inch/ft	0-30	2	Greater than 6	Greater than 19	Marginal [illegible] duction [illegible] cultivate[illegible] crops. In[illegible] includes [illegible] listed bel[illegible]
V and VI	Good, fair, and poor	10-20	Any	Greater than 2.0 inches irrigated. Greater than 4.0 inches dryland	0-60	2	Greater than 4ETp (irrig). Greater than 8ETa (dryland)	Greater than 10	Pasture, r[illegible] woodlan[illegible] respond [illegible] managem[illegible]
VII	Good, fair, and poor	10-40	Any	Greater than 1.0 inch dryland	0-75	2-3	Less than 4ETa (dryland)	Less than 10	Pasture, [illegible] woodlan[illegible] do not re[illegible] to manag[illegible]
VIII	Good, fair, poor, and unsuitable	10-40	Any	Any	0-100	2-3	Less than 4ETa (dryland)		No produ[illegible] of value

commendations and concerns noted by searchers.

ow intensely should the soils and overburden sampled?

Sampling intensity depends on State and Fed- al regulations; the amount of disturbance pected; problems foreseen on the site; and the sampling needs of other members of the inter-disciplinary team. The object is to obtain a general knowledge of the soils and overburden and to detect inhibitory zones in the overburden.

Discussion:

It is recommended that the major soil horizons be sampled. State or Federal regulations,

Table 11. — *Soil material suitability for salvage and reclamation use*

nition: Suitability, as defined, is the qualities and properties of natural soils or soil material that chemically and physically provide necessary water and nutrient supply for the top growth and root development of plants.

eria: The following groups of ratings are indicators of potential quality of natural soil profiles, certain soil horizons, or the erlying parent material, disregarding nutrient levels.

	Levels of suitability[1]			
or ameters	Good	Fair	Poor	Unsuitable
A soil texture	Fine sandy loam, very fine sandy loam, loam, silt loam, sandy loam	Clay loam, sandy clay loam, silty clay loam	Sandy, loamy sand, sandy clay, silty clay, clay	Clay textured soils with more than 60% clay
nity (mmho/ r	Less than 3	3-6	6-9	More than 9
linity (exchange- sodium per- age, ESP)	Less than 4	4-8	8-12	More than 12
centration of or undesirable ents, i.e., n, selenium, ar- , % lime, etc.	Very low	Low	Moderate	High
pH	6.1-7.8	5.1-6.1 7.9-8.4	4.5-5.0 8.5-9.0	Less than 4.5 More than 9.1
itional para- ers to be evaluated				
t consistency	Very friable, friable	Loose, firm	Very firm, extremely firm	
ose fragments, % olume	0-10	10-20	20-35	More than 35
able water- tion capacity /inch)	More than 0-16	0.08-0.16	Less than 0.8	
eability n/hr)	0.6-6.0	0.2-0.6	Less than 0.2 or greater than 6.0	
nic matter (%)	More than 1.5	0.5-1.5	Less than 0.5	
structure	Granular, crumb	Platy, blocky, prismatic	Massive, single grain	

[1] tings may be raised one class if soil amendments or management practices can be applied to overcome the limitations.

however, may require that transition horizons also be sampled. In particular, any horizon that contains crystalline salts should be sampled.

If there is not enough time between announcement of mining and commencement of work to sample and complete lab analysis—and there is no way to negotiate for more time—soil characteristics may have to be inferred from other, similar areas where series or phases of families have already been established. The intent is to characterize the soils and overburden on a representative basis, which is a judgmental assessment that relies on professional experience. The techniques are the same as in soil-mapping work, which is satisfactory if 85-percent accuracy is maintained.

Normally, sampling intensities are too low to assure complete accuracy in predicting inhibitory zones—i.e., zones in the overburden that would prevent or limit plant growth if used as a growing medium. For example, work done at Montana State University indicates that successful (90 percent) characterization of the location of inhibitory zones was attained only when the intensity of the grid sampling approached 100-200 ft between sample sites (see fig. 6). The reason for this is that inhibitory zones, such as pockets of highly saline material, will often be found in locations not predicted by examination of rock structures obtained from more widely spaced core samples.

This type of sampling intensity is very expensive, however, and is probably not feasible in most mining situations. Thus, sampling efforts may have to be intensified during postmining spoils analysis to identify and handle the inhibitory material that may surface (see chapter 5).

One alternative to such intense grid sampling is an incremental system of drilling, in which a small number of holes is sampled and evaluated, and then more drilling is ordered based on the results of the first cores. In other words, random samples are taken on a less intense basis and then the soils scientist and geologist make a decision on the level of further sampling needed based on the first round of samples.

Another method used is to classify surface materials (dark shales, light shales, sandy materials, etc.) before sampling because often these surface materials will correlate with the ov burden strata found under them. This procedu can reduce the number of samples needed compared to a random or fixed-grid type sampling.

How should the soils samples be sent to the lab

Paired profiles and individual samples of ea horizon should be sent to the lab if possible.

Discussion:

Paired profiles are two complete cores repi senting two entire profiles and taken from t same sampling area. Then, the profiles a separated into horizons, and each sample pair horizons is analyzed. In this way, results fro the lab tests on the paired horizons can compared.

Additional Information:

Recommended references for this chapt include:

"Procedures Recommended for Overburd and Hydrologic Studies of Surface Mines," James Barrett, Paul E. Deutsch, Frank Ethridge, William T. Franklin, Robert D. He David B. McWhorter, and Daniel Youngbe Colorado State University and USDA For. Ser Douglas, Wyo. December 1978.

"Laboratory Methods Recommended f Chemical Analysis of Mineland Spoils a Overburden," U.S. Dep. Agric. Handbook 5

"Methods of Soils Analysis," Amer. S Agronomy. Publication 9. 1965.

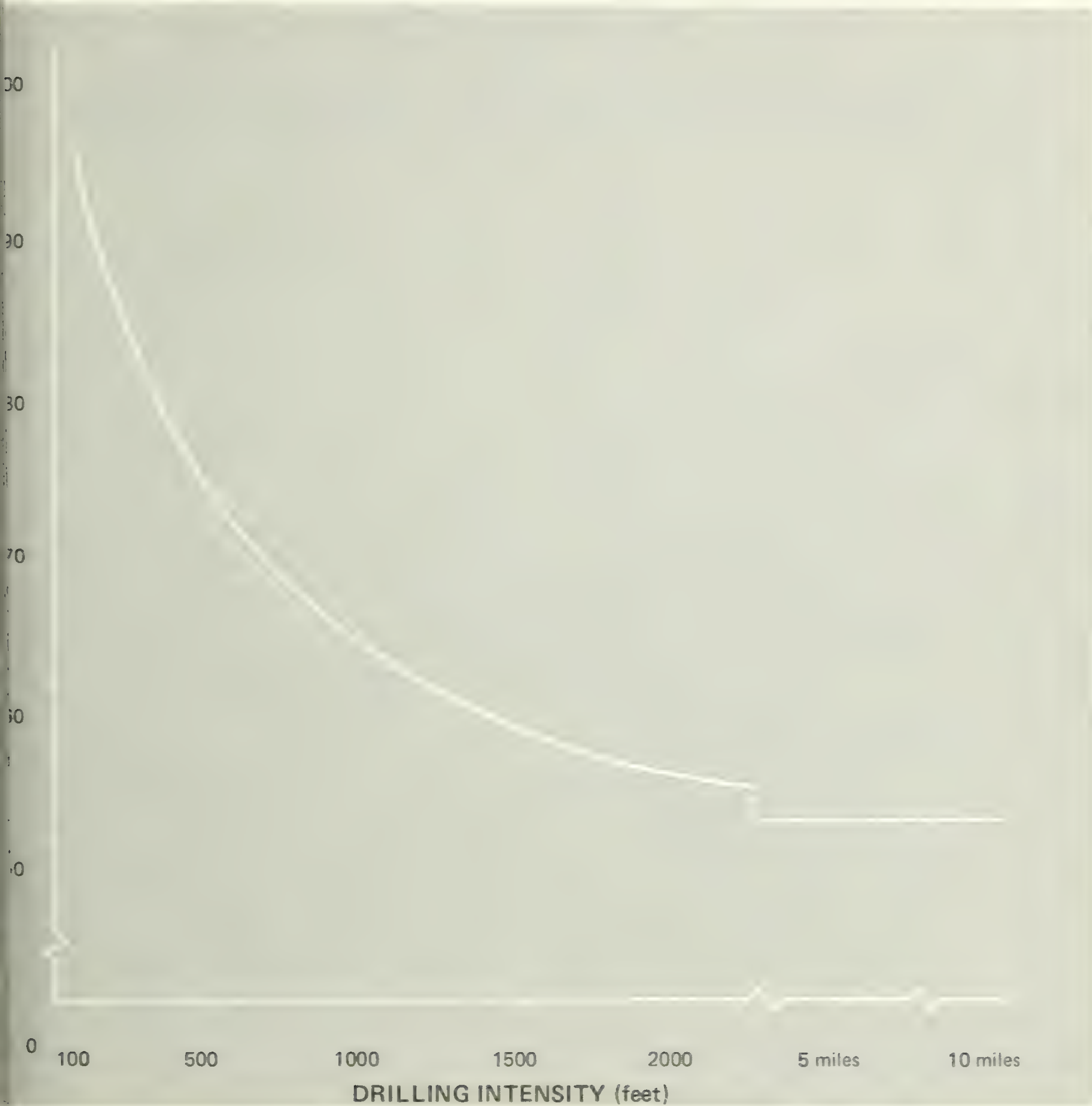
"Salinity Manual," U.S. Dep. Agr Handbook 60.

"Soil Taxonomy," U.S. Dep. Agr Handbook 436.

"Soils Survey Laboratory Methods a Procedures for Collecting Soils Samples," US Soil Conser. Ser., Soil Survey Investigat Report No. 1. Revised 1967.

"The Place of the Laboratory in S Classification and Interpretation," by Charles Kellogg. USDA Soil Conser. Ser., Washingt D.C. June 1962.

"Soil Interpretations in the Soil Survey," Charles E. Kellogg, USDA Soil Conser. S Washington, D.C. April 1961.



r6. Accuracy in characterizing overburden based on sampling intensity. (D.J. Dollhopf, Montana State University)

Chapter 3
SELECTING STORAGE AREAS

hapter Organizer: Sonny J. O'Neal

ajor Contributors: Sonny J. O'Neal, James Butler

An important component of the mining plan the selection of storage sites for the mined aterials. Although the mining operator gener-ly selects the site best suited to his needs, proving this selection is the responsibility of e land manager, based on recommendations om the soils scientist and other members of e interdisciplinary team. The ID team should so be prepared to suggest alternative storage eas. This process should be followed regardless the size of the proposed operation.

hat are the goals of storage area selection?

In general, the goals for selecting storage areas ould include: providing safety and preventing dangerment of adjacent property, life, and sources; accommodating reclamation that will ovide for land uses and esthetics compatible th surrounding lands; assuring compliance th State and Federal regulations; providing r adequate access to and from the storage area; d considering the mining company's feasibility timates.

iscussion:

Not all State laws require that ultimate clamation, including the reclamation of orage areas, be compatible with surrounding d uses. By working with the mining operator design a suitable storage area and by identify-g alternative storage sites, however, the land anager should be able to insure that the site ll be compatible with its own land-nagement goals. Of course, any specific laws rtaining to selecting a storage area, such as vironmental Protection Agency (EPA) regula-ns on sediment, should be outlined well fore site selection begins.

What kinds of storage areas will the soils scientist aid in selecting?

Storage areas may be temporary or permanent, fluid or dry. Some storage areas may simply be filled by dumping; others will be constructed in lifts and mechanically compacted at various stages. Selection criteria will vary based on the type of storage planned. For example, if storage will be temporary, the soils scientist should ask if it can be reclaimed after the material is removed; if permanent, he should determine if the material itself can be revegetated, and if suitable soil material should be stripped from the storage site for rehabilitation use.

Discussion:

Temporary storage areas include:

• Temporary storage of topsoil until it can be replaced on the mined site.

• Temporary storage of overburden. Although not a common practice, there are situations when overburden must be stored and later placed in the mining pit as backfill.

• Temporary storage of ore prior to shipment to a processing plant.

Permanent storage areas include:

• Permanent storage of overburden. Mine operations with large stripping ratios and deep pits require external waste dumps that are permanent; i.e., the material cannot be placed back into the pit as backfill. Another case in which the mine is not returned to its original contour by backfilling is when it may be mined again several years later.

• Tailings ponds. Fluid material, such as mill tailings, is usually impounded behind embankments for drying if it cannot be pumped back into the mine.

Prior to storage selection, what factors should be analyzed by the soils scientist in cooperation with the ID team?

The soils scientist should work with the ID team to provide information on:

• Whether storage needs will be permanent or temporary.

• The quantity and characteristics of the material to be stored.

• Potential toxicity or stability problems once the material is in place.

• Suitability and feasibility of removing topsoil from the site for later use in reclamation.

• Materials placement methods.

• Recommended slope and aspect of the fill.

• Current vegetative productivity of potential storage areas and predictions on the success of reclaiming the storage area.

• Access from the mine operation to the storage site. Also, consider removal access if the storage is temporary.

• Effects of existing topography on future stability and reclamation.

• Effect of wind and water on the storage site and the feasibility of erosion control practices to prevent sediment from leaving the site.

• Effects of drifting snow and whether snow management is needed.

• Drainage effects on stability and reclamation.

• Effects of material storage on adjacent land uses.

• Effect of leachates from the storage material entering the water supply.

• Effect of existing vegetation on waste dump stability—clearing or other site preparation needs.

Discussion:

Both physical and chemical characteristics of the material to be stored should be known in order to design a stable dump that will support vegetation, especially if the storage area will be permanent. Although complete accuracy in characterizing the material that will be stored is not possible until it is actually in place, a broad estimate of its characteristics, including erodibility, acidity, or alkalinity, and competency, can be determined based on analysis of the soil and overburden at the site to be mined. If toxicity and competency problems are foreseen on a site, it should be avoided as a storage area, or the dump design should adequately resolve these problems.

Generally, the existing topsoil at the mine site will be the most productive growing medium for plants and should be stockpiled for placement back on the site as topsoil.There are cases, however, when analysis of the overburden identify substrata that can be used as a p growth medium in lieu of topsoil. If this i case, consult with the mining engineer or feasibility of stockpiling these materials for use as topsoil, if they cannot be placed or during the mining process.

Current productivity of potential st areas and the potential for reclaiming the st area should be determined with input fron vegetation specialist. The ID team should d if the site's plant productivity can be sacri to becoming a storage area. Characteristi both the current site and the material pla for storage at the site will aid in determ reclamation potential of the storage area.

It is recommended that the storage ar no steeper than 3:1. The slope of the fill not be so steep that, as the dump settles, ment loss and surface slides occur (fig. 7). slope should also be shaped in such a way it is compatible with surrounding land fo tions and should not create a barrier to life habitat or water-drainage patterns. A interaction with the ID team is mandatory.

Consideration should also be given to direction of the slope. For example, a s facing slope will be more difficult to reveg in arid climates because of the higher tem tures common to southern exposures. N facing slopes may have disadvantages in climates where growing seasons are short.

Wind can be a problem if fine-grade mat are left on the surface of the storage areas. materials can then blow onto and po adjacent land and watercourses. If soil er from water movement is foreseen, the scientist and mining engineer should dete if a sediment basin below the storage are be built to catch eroding sediment, or if shaping will prevent or minimize erosion.

Regarding the effects of leachates fror stockpiles, consult with the hydrologist to dict the possibility of leachates enterin adversely affecting water supplies.

Additional Information:

Refer to chapter 2 of this guide for recommended to characterize soils overburden.

What information should the soils sci

rovide after the site, or the most viable alteratives, have been chosen?

At this point, the soils scientist may need to d the land manager and the ID team in conucting site and foundation investigations in ore depth, and making recommendations for aterials handling. (See chapter 4.)

Discussion:

If more information is needed to make a final decision on the acceptability of the storage site, subsurface investigations may be needed. The following information may be available from the mining engineer or engineering geologist:

- Depth to bedrock.

Figure 7. A potential result of very steep dumps is rill erosion and mass slumping from saturation due to snowmelt water.

• Materials properties (distribution analysis by three-dimensional mapping of materials, shear strength, and consolidation characteristics).

• Ground water.

• Bedrock properties.

Once the site has been selected, it is important to make sure that all existing vegetation will be removed from the site before any material is stored on it. If this is not done, the resulting decaying material may create a slippage plane and piping underneath the dump. Also, when organic matter is pressed onto the surface by fill material before it has decomposed, it tends to seal the soil material under it, and water will not percolate through it. Consideration should also be given to the possible effects of erosion from the site in the interim between removal of the vegetation and dumping the spoils.

Such factors as the chemical and physical reaction of the spoils once placed on the site should be predicted before placing mined material into the storage area. In addition, it is important to consider the color and texture of the material that will become topsoil on the site because this will affect vegetation growth. And, at this time, the possibility of selective handling of any toxic or inhibitory material should be considered. The following chapter will provide more information on selective handling.

Chapter 4
MATERIALS HANDLING

apter Organizer: Douglas J. Dollhopf

or Contributor: Douglas J. Dollhopf

orrect handling of the soils and overburden the mining operator is increasingly being phasized in reclamation programs today, ause reclamation implies reclamation from bottom of the pit to the top and expressly siders the physical, chemical, and hydrologic racteristics of lands both before and after ing. For example, one reason for expanding amation efforts beyond simply producing ble and useful vegetation on the surface is concern that mining operations may adverse- ffect the quality of ground-water resources.

his concern stems from the fact that, in es, the mineral seam itself was an important ifer prior to mining. During mining, however, mineral seam is effectively eliminated and aced by overburden material from an adja- t mine cut. The aquifer then tends to reestab- itself in the new spoil medium, and it is sible that the ground water will take on, to a ain extent, the chemical characteristics of low medium. Thus, it is imperative to deter- e the location of chemically undesirable burden zones to insure that materials from zones are not deposited in the pit base re an aquifer may reestablish. (These zones be referred to as inhibitory zones in this pter.) It is also imperative that any unde- ble overburden is not deposited within the t-root zones if it is known that it will severe- nhibit the revegetation process, or if the tation may accumulate certain chemicals will harm livestock or wildlife when grazed.

nother concern, of course, is the cost lved in selective handling of inhibitory s. For example, recent research indicates selective handling may add from 12 to 53 ent to the direct operating costs of mining. s, based on premining analysis results, the mining operator and land-management team must decide the cost/benefit of such an undertaking.

How are inhibitory zones located?

Field and laboratory analyses of the soils and overburden will aid the soils scientist in estimating the extent and location of inhibitory zones in the material prior to mining. Additional observation and testing during the mining operation may also uncover previously undetected inhibitory zones.

Discussion:

As discussed in chapter 2, sampling methods cannot guarantee total accuracy in characterizing the overburden, unless a very intensive—and expensive—sampling program is undertaken. Because of these limitations, defining the extent of inhibitory zones may be the most difficult part of the materials placement program. In addition to the inaccuracy of most sampling frequencies, there are times when sample collection is only hours ahead of the dragline. For instance, the samples are collected from a blast hole drill rig. In contrast, preparation for any selective handling takes several days, when time needed for both chemical analysis and engineering plans is taken into account.

To help ease this dilemma, the following procedures are recommended:

- Develop sampling and rapid analysis methodology to adequately define problem zones within the overburden.
- Determine the premining hydrologic characteristics of the site in order to estimate post-mining conditions. Work with a hydrologist on these characterizations.
- If possible, develop a plan to alter normal mining operations, when necessary, in order to provide sufficient time for sample collection and analysis.
- Work with a mining engineer on these plans.

Must inhibitory zones always be selectively handled?

No, research shows that unless an inhibitory zone constitutes 15 percent or more of the overburden material, it may be sufficiently diluted in the materials handling and mixing process and not adversely affect ground water or plant growth.

Discussion:

Because selective burial of inhibitory zones in the overburden in order to hydrologically isolate such materials may cost 1.1 to 1.5 times more than the normal spoiling operation, it is important to determine whether normal dragline spoiling can sufficiently mix problem materials and produce an environmentally acceptable spoil profile.

Prior to strip mining, overburden is usually composed of a more or less orderly array of approximately horizontal rock strata. These strata may contain material that exceeds levels considered potentially harmful or inhibitory to plant growth; however on the undisturbed site, they are generally below the biologically active surface zone.

During mining, there is a tendency for the stratigraphic sequence to be inverted as the overburden is transferred into spoil piles; however, such strata are not transferred as whole units. Rather, several strata may be crossed by the dragline bucket as it is filled and successive loads are collected from varying depths. Digging and spoiling of the overburden tend to mix the original stratigraphic conditions. The result is spoils of increased chemical and physical homogeneity; hence, potential toxicity may be reduced to acceptable levels, which are neither harmful to plant growth or to water quality.

Research has shown that when the problem material constitutes less than 5 percent of the total overburden volume, such material is essentially not detectable in the spoil pile. Problem materials constituting 5-15 percent of the bulk mass could be detected in the spoil mass 50 percent of the time, but the volume of the problem material detected was generally less than that found in the overburden, indicating partial dilution. Problem material exceeding 15 percent of the overburden volume, however, was always detected in the spoil mass, but usually to a lesser degree than that found in the undisturbed ov[illegible] burden. These criteria were developed at a mi[illegible] which used a large dragline to excavate overb[illegible] den. Other methods of excavation, such as tru[illegible] and shovel, may change these criteria.

How can maximum dilution of inhibitory m[illegible] terial be achieved without selective handling?

It has been found that scatter spoiling m[illegible] produce a better degree of mixing and diluti[illegible] although the difference is not great. Nor[illegible] spoiling has an effect similar to scatter spoili[illegible] Dump spoiling generally results in less mix[illegible] of inhibitory zones and thus should be m[illegible] mized in dragline spoiling operations.

Discussion:

Scatter spoiling generally spreads each buck[illegible] load of material over an area in the spoil [illegible] about 45-65 yd long by 10 yd wide. In orde[illegible] spread the overburden this widely, the drag[illegible] continues its swing while unloading. The op[illegible] tor controls the rate of the load leaving [illegible] bucket and, hence, the amount of spread[illegible] Normal dragline spoiling is similar to sca[illegible] spoiling except that the budketload of mate[illegible] is cast over a smaller area—approximately 2[illegible] long by 10 yd wide.

Dump spoiling occurs when the materia[illegible] dropped when the bucket is nearly station[illegible] and thus the dumped material forms a co[illegible] Generally, dump spoiling is used at the bot[illegible] of a backfill pit because it provides a bas[illegible] material that is less likely to slump or se[illegible] Once this initial fill is in place, normal or s[illegible] ter spoiling methods are generally used for [illegible] bulk of the overburden.

If inhibitory zones in the overburden m[illegible] be selectively handled, how is this done?

The mining engineer, hydrologist, and [illegible] scientist should work together to determ[illegible] where and how the material can be selecti[illegible] buried. Two considerations are: should [illegible] material be buried at some intermediate de[illegible] in the spoils pile; or should it be buried and [illegible] lated from the hydrologic environment b[illegible] impermeable layer of material?

Discussion:

Selective handling of inhibitory material [illegible] add about 12 percent to the direct opera[illegible]

s of mining; if the material is capped, costs increase by about 53 percent. Thus, it is ortant to consider the cost/benefit of such peration.

n understanding of the shallow ground- er system is also essential for evaluation and ementation of selective overburden han- g. A determination of such factors as post- ng water levels, recharge, and water-move- t characteristics in both the undisturbed reconstructed aquifers is necessary to decide the material should be selectively handled if it must be capped. If it is to be capped, ing material must be available and suitable.

general, if the inhibitory material is in a environment, where an aquifer may move ugh it, it may be desirable to envelop the erial with a semi- or relatively impermeable . The soils scientist and engineer can con- ite their expertise to accomplish the project.

s one example, the following procedure was on a coal-mine site that was hydrologically e—it tended to form an aquifer through the of the pit—and the overburden contained a zone of excess salts. (Also see fig. 8-21.)

- Quality material was placed in the base of the pit to a thickness that would be greater than the expected thickness of the reconstructed aquifer—in this case, 40 ft.
- The salt material was selectively dug up and applied to the top of the 40 ft fill.
- At times, the dragline was shut down so that a dozer could go into the pit and grade the materials.
- A clay cap was constructed on top of the salt so that any percolating waters or a perched aquifer would not interact with the salt material. Once again, the dragline was periodically shut down so that scrapers could bring in the clay from another part of the mine.

In essence, then, the problem zone was buried above the aquifer and yet below the ultimate root zone. Obviously, this was a very expensive operation.

It should also be noted: If the material is to be selectively handled, the techniques for doing this must be clearly communicated to the mining crew and equipment operators.

Figures 8-21. Demonstration of selective handling procedure at a coal-mine site in Montana. (D.J. Dollhopf, Montana State University, Research Report 125).

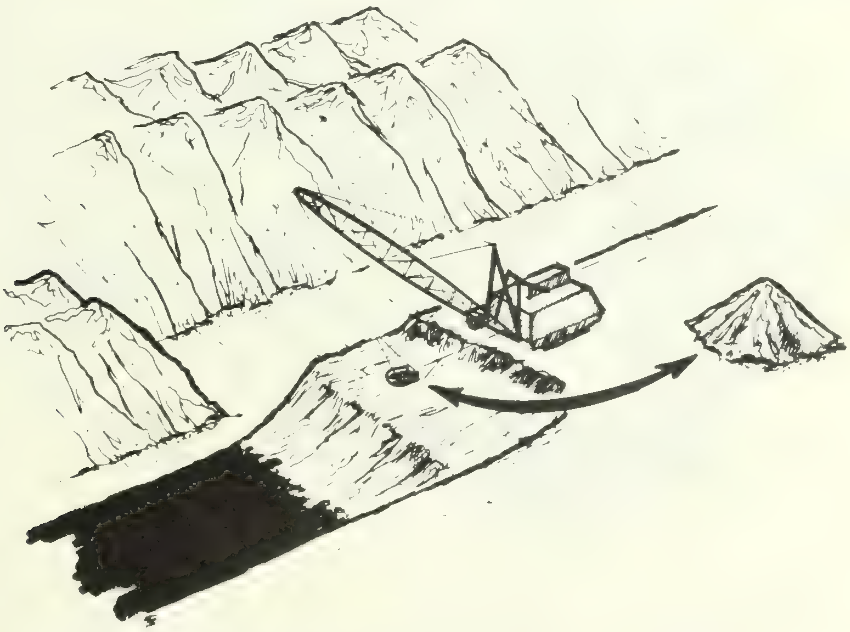


Figure 8. Initially, the dragline stockpiled the surface 5 yd of salt material on the highwall.

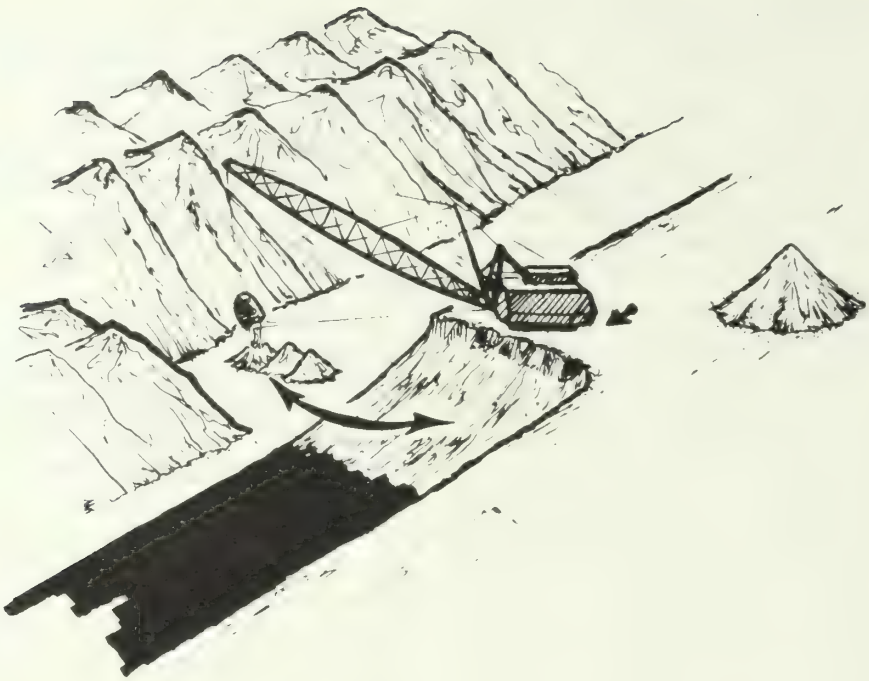


Figure 9. Overburden below the surface salt-affected zone was placed in the pit bottom as basement fill.

Figure 10. Leveling and shaping the basement material
with the dragline to reduce the work required by a dozer in grading these materials.

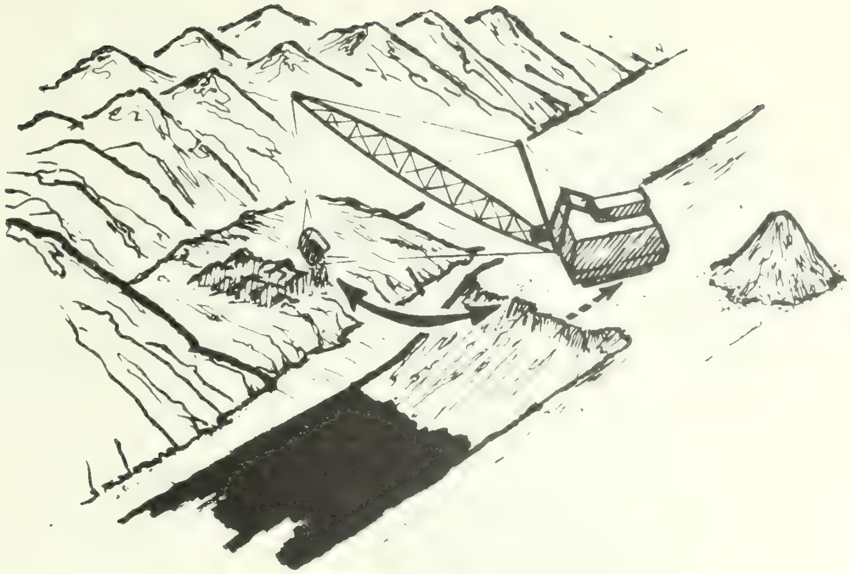


Figure 11. Direct deposition of saline material on the basement fill.

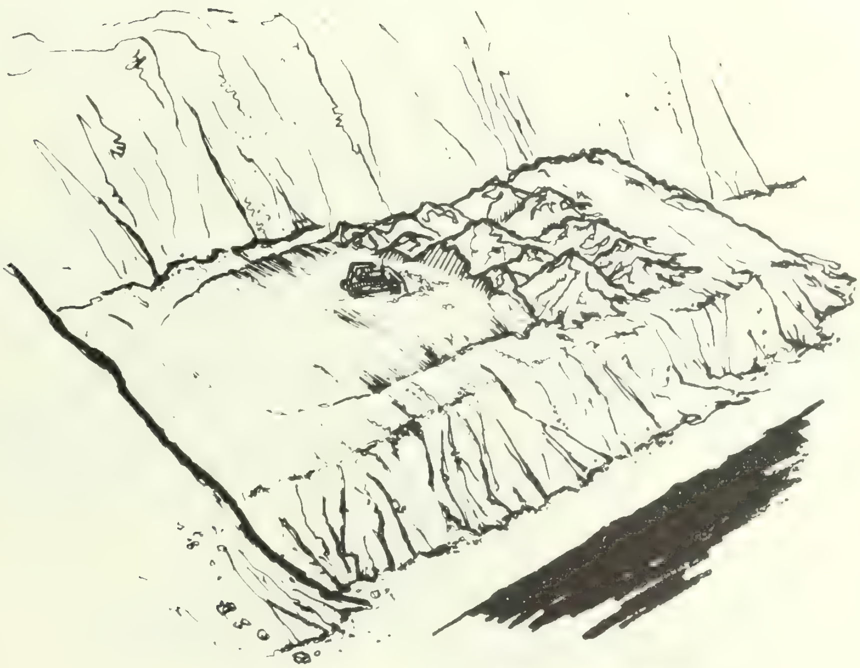


Figure 12. The salt-affected material was shaped to a 5:1 grade with a D-9 dozer.

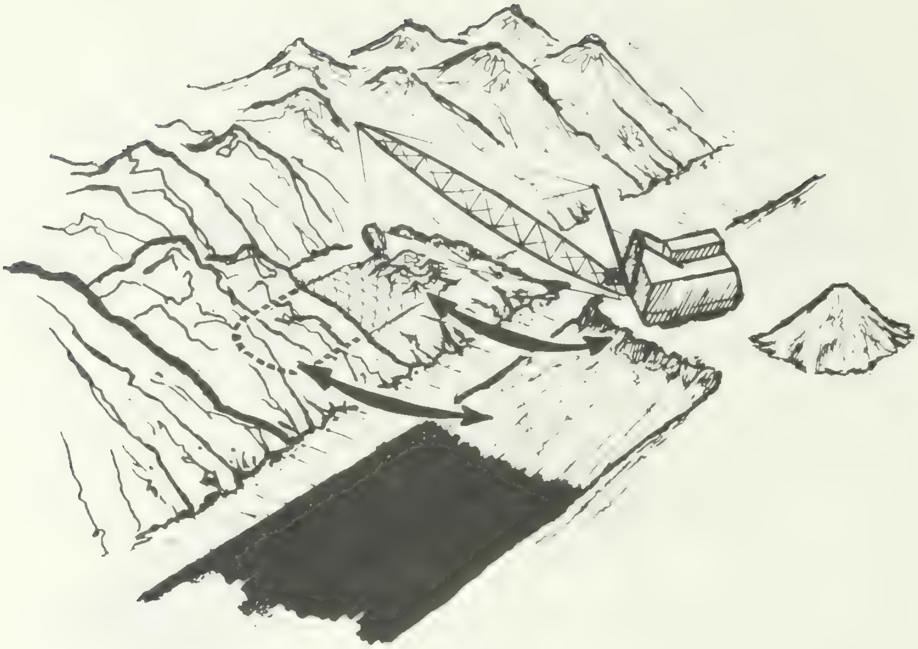


Figure 13. Burial of saline material (lower arrow) with nonsaline overburden.

Figure 14. Deposition of saline material from both the overburden and the stockpile.

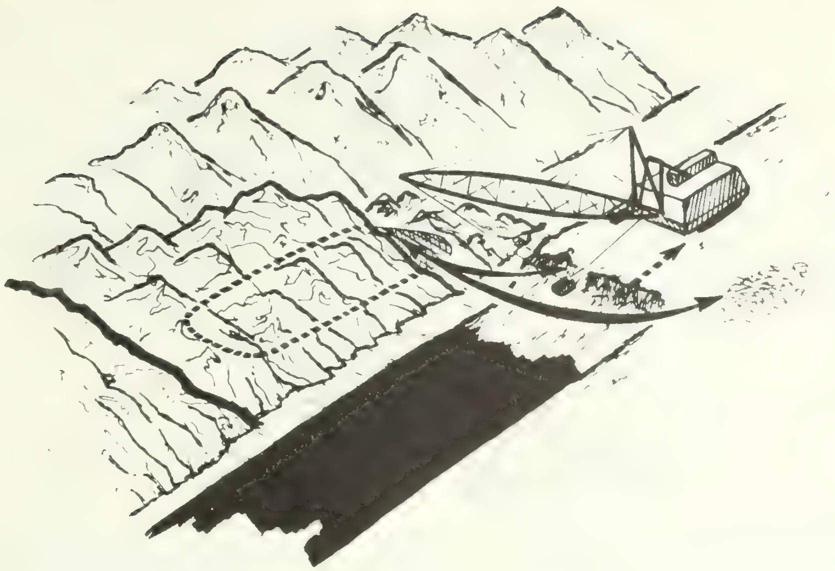


Figure 15. Most of the highwall stockpile was deposited on the basement fill towards the completion of the uncapped study.

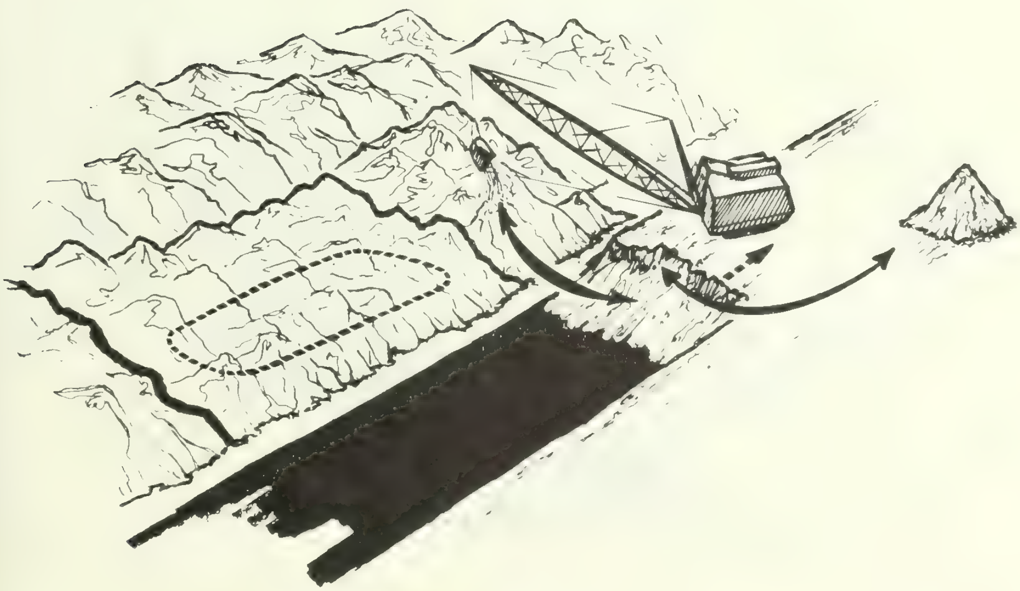


Figure 16. A buffer zone was constructed when the ıcapped study was completed. During this phase the surface saline zone was stockpiled on the highwall.

Figure 17. Following construction of the buffer zone, a 15-yd-thick basement fill for the capped research area was deposited in the pit bottom. During this process, the surficial saline zone was stockpiled on the highwall.

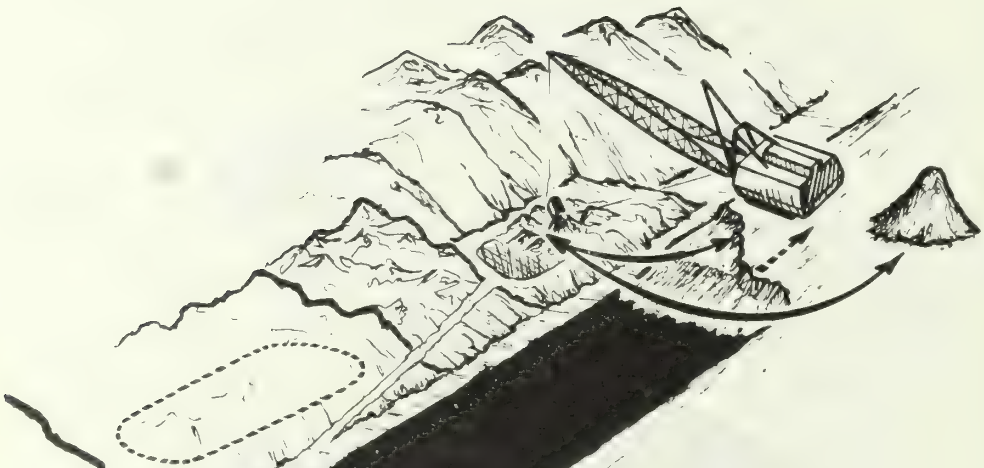


Figure 18. When a portion of the basement bench was completed for the capped study, the dragline deposi saline material over the basement from both the overburden and stockpile.

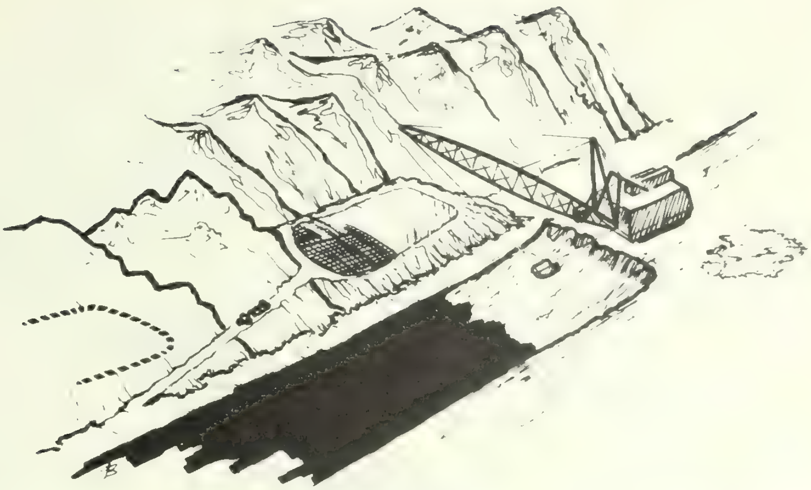


Figure 19. Clay located 110 yd from the demonstration site was applied to a depth of 2-1/2 ft by scrapers. The dragline had to shut down during this clay-capping operation.

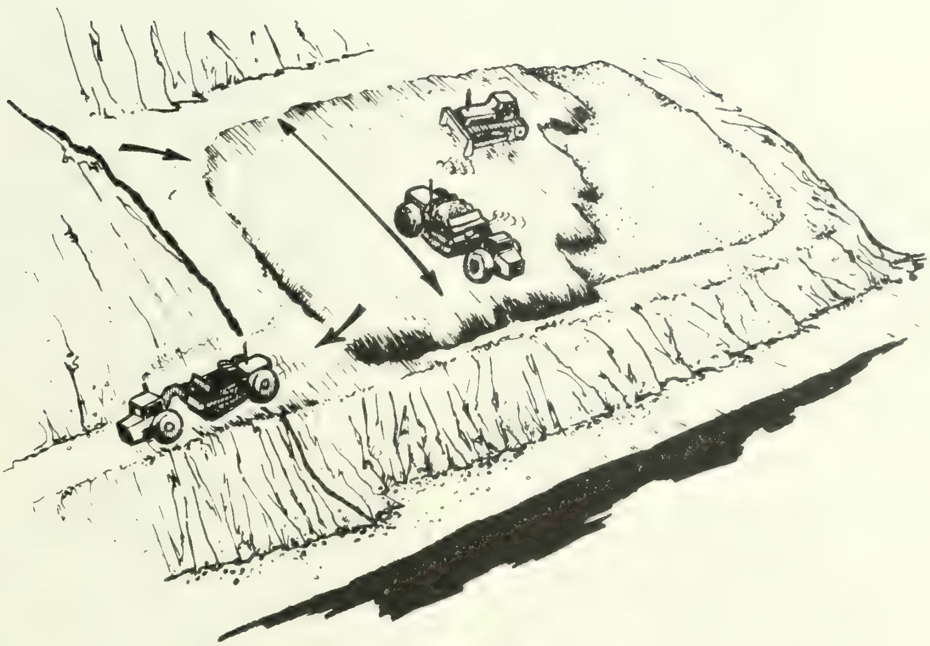


Figure 20. Loaded scrapers were used to compact the clay cap. A D-9 dozer shaped the cap to produce an umbrella effect over the saline material.

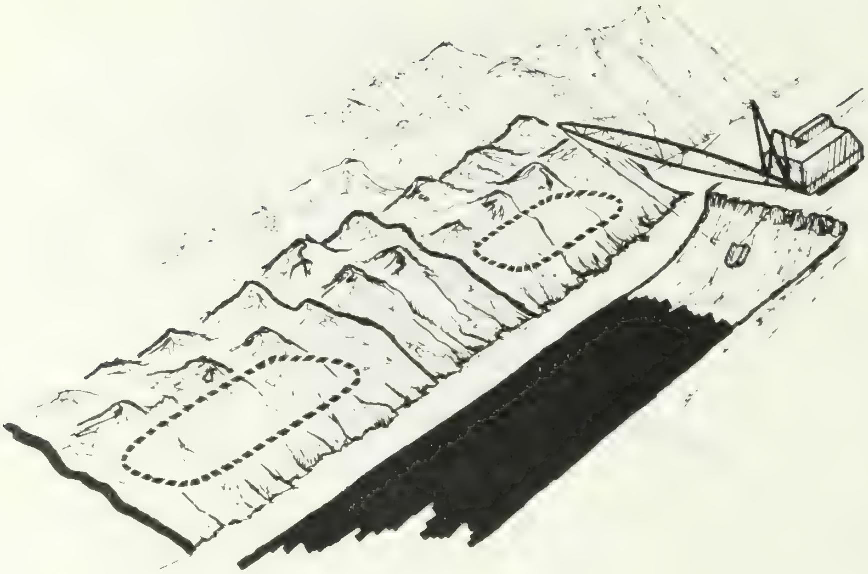


Figure 21. The uncapped and capped experiments were oriented as shown above at the conclusion of the demonstration.

Should topsoil be selectively handled?

Generally, yes, because this material is usually the most superior plant-growth medium and thus should be replaced on top of the spoils. The analysis process to determine whether the topsoil will be the best plant-growth medium is covered in chapter 2.

Discussion:

Because a suitable plant-growth medium is essential to rehabilitation, and soils develop very slowly in the arid West, the topsoil is a highly valuable resource. Topsoil can either be removed from the active mining area and immediately spread over freshly graded spoils, or it can be stockpiled for later application. The former method is preferable because fresh topsoil contains live seeds and plants that will take root and aid in stabilizing the site. In many cases, however, topsoil stockpiling is the only choice. If topsoil is stockpiled, it should be stabilized through grading, mulching, and possibly seeding it with a fast establishing, temporary grass.

In certain instances, a subsoil material may be identified as a suitable plant-growth medium. If so, and it is feasible to selectively handle it, the material can be stockpiled and graded on the surface of the spoils in the same manner as topsoil is handled.

Additional Information:

Tests to determine the quality and amount of topsoil material that should be saved and replaced on the mined site are discussed in chapter 2. More information on spoils surfacing is provided in chapter 7.

Information on selective handling techniques are provided in:

"Selective Placement of Coal Stripmine Overburden in Montana—II. Initial Field Demonstration," by D.J. Dollhopf, W.D. Call, C.A. Cull, and R.D. Hodder, Montana Agricultural Experiment Station, Montana State University, Bozeman, Mont. Research Report #125. June 1977.

"Selective Placement of Coal Stripmine Overburden in Montana—III. Spoil Mixing Phenomena," by D.J. Dollhopf, J.D. Goering, J. Levine, B.J. Bauman, D.W. Hedberg, and R.L. Hodder, Montana Agricultural Experiment Station, Montana State University, Bozeman, Mont. Research Report #135. June 1978.

Chapter 5
SPOILS ANALYSIS

Chapter Organizer: David G. Scholl

Major Contributors: David G. Scholl, E. Gary Robbins

As discussed earlier in this guide, soils and overburden analysis is necessary in the premining phase of the operation in order to predict what characteristics the spoils material will exhibit after mining. It also indicates whether any special handling will be required during mining. Another series of tests must be run, however, when the spoils are placed in the fill to determine if premining predictions were correct. Unfortunately, much research remains to be done in the area of correlation between soils analysis and plant response. In addition, no systematic method of spoils classification has been fully developed. Some general principles have emerged, however.

What is the purpose of spoils analysis?

After the spoils have been placed in the storage area, they should be analyzed to pinpoint problems or beneficial characteristics and to determine if premining predictions and reclamation methods outlined in the mining plan are still valid. If not, some modification may be required in order to successfully revegetate and manage the site. In other words, these studies produce the new baseline by which the site can be managed.

Discussion:

When the soils and overburden were analyzed prior to mining, some indication of problems and opportunities in the spoils material may have been predicted. Once the material is in place, the spoils should be tested to see if the desired effect was achieved. For example, were problem materials buried below the plant rooting zone and above any important aquifers, or were they diluted during the mining process?

How is the spoil material analyzed?

Knowledge of the characteristics of the soils and overburden prior to mining and the techniques used to distribute the spoils on the site during mining will help the soils scientist make a preliminary analysis of the spoils. Field observations, and a sampling and lab-testing program, should also be undertaken.

Discussion:

If one knows what the geologic profile of the overburden was prior to mining and how the material was deposited and regraded, one can predict what materials will show up in the spoils material. Of course, this material will now be mixed in complex ways and classification will be difficult, but a preliminary analysis may be done by on-site inspection. For example, the soils scientist can use a standard soil survey practice of traversing the area, exposing pits in the spoils material, and observing the nature of existing profiles.

In one situation, a soils scientist observed an interbedding of shale and sandstone in the overburden profile on a coal-mine site. The shales were segregated by color—darker gray shales were often the unoxidized material from the lowest part of the overburden profile and were likely to be a problem material because of rapid dispersion of the clay and high sodium levels. The lighter colored shales, in contrast, had undergone more leaching and thus were a more amendable material. The sandstone and residual coal in the spoil material could also be visually categorized.

In this way, the spoils analysis was aided by noting the color and texture of the materials in the dump and relating this information back to the specialist's knowledge of the type of material in the soils and overburden.

Exception: In some cases, mixing the spoils will result in a material that is essentially

all one color. In addition, caution should be exercised when relying on visual observation alone. In some cases, materials that look similar will exhibit widely different chemical characteristics when tested in the lab.

It is important to set up a standard method of sampling, testing, and interpretation so that the samples can be accurately compared to one another.

What sampling intensity and frequency are necessary?

Sampling intensity and frequency depend on legal requirements, the plant-rooting depths of the vegetation planned for the site, hydrologic considerations, the intensity of sampling used during premining analysis of soils and overburden, monitoring plans for the site, and professional judgment that a representative characterization has been made.

Discussion:

Legal requirements may dictate both intensity of sampling, including depth and spacing, and how often the spoils must be tested over time. If legal requirements do not apply, samples should be taken at least to the depth that the plant roots will reach. Hydrologic considerations will also influence sampling depths, and therefore the hydrologist should assist in determining this factor.

When relating spoils testing intensities to the intensity of sampling soils and overburden prior to mining, it is important to remember that if the sampling was widely spaced during premining analysis, inhibitory zones in the material may have been undetected. In such a case, a more intense sampling of the spoils may be necessary to determine if there are problem materials that must be treated.

The soils scientist should also decide if a spoils testing program should be set up to analyze and monitor the material for changes over time, based on his knowledge of the likelihood of a long-term problem at the site.

What should be done with the spoils samp[illegible] once they are collected?

The soils scientist, hydrologist, and vegetati[illegible] specialist can outline what parameters should [illegible] tested for, based on their knowledge of the ch[illegible]acteristics of the site prior to mining and t[illegible] type of vegetation and end use planned for it.

Discussion:

Chemical and physical problems detect[illegible] prior to mining should be tested again to det[illegible]mine whether the problems were mitigated [illegible] the mineral was mined. In addition, consult w[illegible] a hydrologist to determine if specific hydrolo[illegible] tests are needed.

How are the results of spoils analysis used?

The results should be used to set up an app[illegible]priate spoils treatment program, to determ[illegible] what vegetative species will best adapt to [illegible] site, and to outline what management practi[illegible] are needed to maintain the established produ[illegible]vity and to protect the site from erosion. [illegible]f course, requirements stipulated by law in [illegible] regard must also be consulted.

Discussion:

Although precise interpretations of sp[illegible]s analysis tests are difficult, general estimates [illegible]f conditions existing in the spoils material [illegible] possible. Based on these estimations, rev[illegible]tation plans may have to be altered, and cer[illegible]n chemical or physical amendments may [illegible] recommended to ameliorate unfavorable co[illegible]tions. In addition, the soils scientist m[illegible]t recommend that certain problem mate[illegible]s either be removed or buried at a greater de[illegible]. Such recommendations often require an alt[illegible]tion of the reclamation plan.

Additional Information:

For more information on analysis of sp[illegible]s, refer to "Laboratory Methods Recommen[illegible]d for Chemical Analysis of Mined-Land S[illegible]ls and Overburden in the Western United Stat[illegible]" U.S. Dep. of Agric., Agriculture Handbook 5[illegible].

Also refer to USDA-Soil Conservation Se[illegible]e Technical Guides for appropriate soil mar[illegible]ement practices. These guides are availabl[illegible]at local Soil Conservation Service offices.

Chapter 6
TREATING SPOILS PROBLEMS

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Based on the results of spoils analysis and on-e observations, the soils scientist may deter-ne that the spoils must be treated in some y prior to planting. Chemical, physical, and ological problems, and some recommended utions, are discussed in this chapter.

Before prescribing any treatment, however, e soils scientist should realize that conditions the site must be both within the physiologi- tolerances of the plants and suitable to the nned land use. In most cases, the goal ll be to return the site to a beneficial use—not rely to get plant materials to grow. As part of s process, new soils will be built from the ils.

Because some species can tolerate less-than-timum conditions, treatments are not al-ys justified; only when the problem is severe ough to prevent permanent establishment of etative cover should special treatments be d. It should also be noted that rehabilitation achieved in phases, and the vegetation treat-nt in progress may be a successional stage in planned process.

CHEMICAL PROBLEMS/TREATMENTS

Included in this section is a discussion of blems and recommended treatments for essive acidity, salt and sodium concentra-ns, and trace metals.

en are treatments for excessive acidity or alinity necessary?

Whether or not the site requires treatments correct an acid or alkaline condition depends on the spoils' characteristics, as indicated by analysis, and the capability of the desired plant species to adapt to these conditions.

Discussion:

Chemical properties of spoil material are a major consideration for vegetation of disturbed sites because acid and alkaline spoil conditions frequently occur in the West. Acid-mine problems are most often associated with ore production from geologic materials containing sulfide minerals, such as uranium, lead, copper, cobalt, iron, chromium, platinum, and other metals. Alkaline spoils are also common to western mining operations. Alkaline problem areas are generally found in arid and semiarid regions where precipitation is insufficient to leach out salts, although they also occur in poorly drained, low-lying areas and high water-table areas due to slow leaching.

The revegetation of such mine sites may require physical and chemical treatments prior to planting as well as selection of adapted plant species. The role of spoil chemistry cannot be overemphasized for successful reclamation of disturbed mine sites. The soils and vegetation specialists must determine the extent of the spoils problems, such as dispersion, metal toxicities, insufficient amounts of essential minerals, and extremes in pH (fig. 22). With this information, it is then possible to formulate soil amendments that will help to ameliorate toxic and other undesired conditions that retard or eliminate plant growth. The following discussion illustrates the importance of understanding the basic soil-spoil environment affecting plant growth, and can serve as an introductory guideline for understanding chemical problems associated with spoil materials.

The parent material of the spoils controls, to a large extent, the chemical properties of the spoil. The productivity of the spoil may also be altered by the action of climate and vegetation. Chemical properties modify the spoil's physical

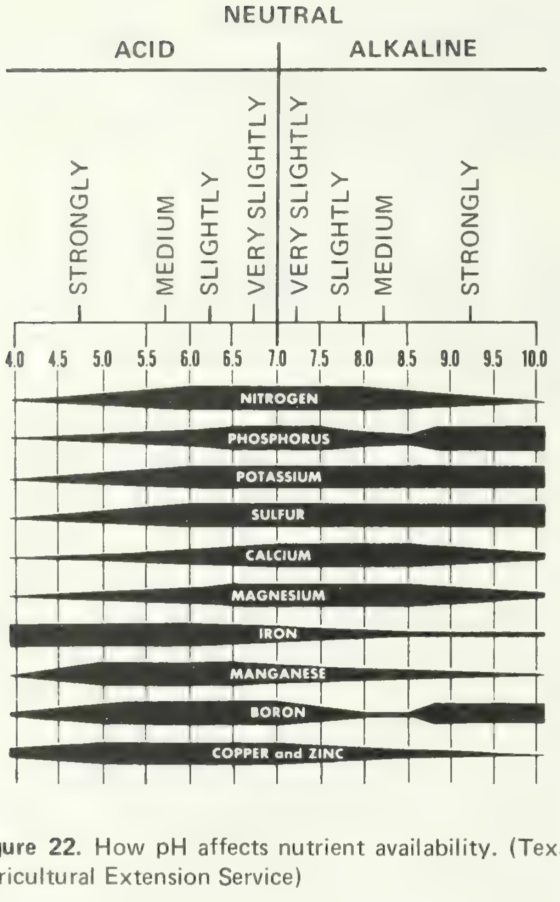

Figure 22. How pH affects nutrient availability. (Texas Agricultural Extension Service)

properties, and the chemical nature of the spoil controls the supply and availability of mineral nutrients for the growth of plants and the relative acidity or alkalinity of the medium.

To determine whether a spoil is acidic or alkaline, soil pH tests can be run, and the results related to those commonly found on undisturbed sites. Undisturbed soils vary widely in pH. The extreme range which might be recorded could be from 3 to 10. Most undisturbed soils fall in the range from 4 to 8.3; most productive soils from 5.5 to 8.3, although some sensitive plants may show chlorosis (yellowing of leaves) above pH 7.5.

• **Acidic spoils.** Spoils on the acid end of the scale—even the ones at pH 3—produce some kinds of plants. At the extremes of acidity, however, production is low, and the number of species is somewhat restricted. In fact, the species contained in a plant community are determined as much by acidity as by any other single soil/spoil property.

The influence of acidity on plant growth is not generally thought to be associated w[illegible] hydrogen ions as such, but to the influence [illegible] acidity on the solubility and plant availabil[illegible] of nutrient elements, such as iron, aluminu[illegible] manganese, and phosphorus. Thus, poor grow[illegible] at very low pH may not be due to excess[illegible] hydrogen-ion concentrations, but to an exc[illegible] and toxicity of iron and aluminum, which [illegible] very soluble at such acidity levels, and to [illegible] lack of phosphorus, which is insoluble un[illegible] such conditions.

• **Alkaline spoils.** Spoils in arid areas will t[illegible] to be basic or alkaline and to remain so beca[illegible] of the lack of water needed to leach the b[illegible] ions after replacement by hydrogen and the pr[illegible]ence of a reserve of basic ions (lime). P[illegible] growth on alkaline spoils is directly relate[illegible] the presence of hydroxyl ions as well as [illegible] solubility and availability of mineral eleme[illegible].

Colloids play an important role in alka[illegible] soils and spoils. A colloid is an extremely sm[illegible] particle of soil with special properties that [illegible] not possessed by larger particles, such as s[illegible] and silt. Soil colloids have negative charges [illegible] act as large, multicharged, insoluble anions. [illegible] negative charges of the soil colloids repel [illegible] negative charges on the anionic particles, [illegible] they are lost with percolating water. Cat[illegible] are positively charged and hence will be hel[illegible] the negatively charged soil colloid. Becaus[illegible] selective adsorption, some elements, such [illegible] sulfur and nitrogen, which are held as su[illegible] (SO_4) and nitrate (NO_3) anions, may be lea[illegible] from the soil and become limiting to p[illegible] growth. Other elements, such as potass[illegible], magnesium, and calcium, are held by the co[illegible] and are not as readily leached from the [illegible]. Plants depend upon this soluble fractio[illegible] their mineral nutrition. Some mineral nutri[illegible], notably nitrate nitrogen, are rapidly lea[illegible] from the root zone. Other elements, such a[illegible]cium, magnesium, potassium, and sodium [illegible] also soluble but are not readily leached be[illegible] they are held by the soil colloid. Soils va[illegible] their capacity to hold nutrient elements d[illegible] two factors: (1) soils vary in their colloid [illegible]tent (clay and organic matter), and (2 [illegible] various kinds of clay and organic matter [illegible] in their exchange capacity.

The kinds of cations which are held o[illegible] surface of the colloid determine the soil [illegible] structural status and the relative acidi[illegible]

alinity of the soil/spoil system. If hydrogen ns are present in the amount of 10 percent more of the total exchange capacity, the soil ll be acid (pH less than 7). If calcium ions ceed all others and there is little, if any, adrbed hydrogen (H+), the soil will be alkaline t will not be alkaline enough to adversely fect most plants (pH will not exceed 8.3). If dium ions predominate, the soil would be disictly alkaline (pH greater than 8.5)—often so kaline that most plant growth is not possible.

Flocculation and dispersion of colloids have actical implications in the use of soils/spoils. hen a soil is under influence of soluble salts in cess of the amount which can be adsorbed on e colloid, the colloid will be flocculated rerdless of the kind of ion which is present, luding sodium. If a soil with an excess of dium chloride is leached, water and dissolved ts will be removed until the excess of salt dissipated. At this time, the colloid will begin disperse and will seal up so tightly that no ore water will move through the soil. Soil lloids also flocculate and disperse in the same nner, with the flocculated condition being e normal and desirable condition and the dissed form somewhat uncommon and definitely undesirable. Dispersion occurs when sodium is, and to a lesser degree potassium ions, dominate on the soil colloid.

High salt concentrations reduce the uptake of ter by plants, retard their growth, or may uce the uptake of nutrients by plants. High centrations of some salts, such as boron, even be toxic to plants. The amount of uble salts that may impair plant growth ends on the type of salts, the type of soil/ il, and the species of plants; however, arbitry guidelines have been established by the . Salinity Lab staff. A soil/spoil is considered ne if the electrical conductivity (EC) of a urated extract is 4 mmho/cm.

odic spoils are a specific type of salt-affected il. They occur when sodium ions are so minant in the spoils that they may adversely ect plant growth. The percentage of sodium is adsorbed on the cation exchange sites of a poil is called the exchangeable sodium pertage (ESP), and if this figure exceeds 10, the ils may be sodic.

Another lab measurement of a sodic spoil is its sodium adsorption ratio (SAR). If the SAR exceeds 10, the spoils may be sodic.

Sodic spoils are highly alkaline. They may be impermeable to water and crust when dry. Any spoil with a pH above 8.5 should be suspected of containing sodium. A spoil dominated by calcium seldom will exceed pH 8.3. A spoil having a pH of 10 will generally not grow plants, will probably be dispersed, and will be extremely difficult to manage.

How are acidic spoils treated?

In much of the West, acid conditions result from the oxidation of sulfide minerals, and these materials must be treated if rehabilitation is to be a success. Generally this treatment involves determining what pH level can be tolerated by the desired plant species and then deciding if a physical and/or chemical treatment will be necessary. Physical treatments limit exposure of the spoil material to oxidation. The most common chemical treatment is the addition of lime in some form to neutralize the acidic condition.

Discussion:

Some plant species, such as lodgepole pine and subalpine fir, will tolerate somewhat acidic conditions. Vegetation specialists can provide information on pH levels that can be tolerated by various plant species.

Before undertaking a treatment program on mined spoils, it is recommended that these treatments be tested on field plots because spoils-treatment requirements may differ substantially from those rates recommended for acidic agricultural soils. Test plots, using plants as indicators of treatment success, will more accurately determine the type and amount of treatment that is effective.

Physical treatments to correct acidic conditions can include the addition of organic matter to the spoil. Topsoiling also adds organic matter as well as burying spoils deeper, thereby further reducing oxidation.

Whenever acid-producing spoils are ripped or harrowed, lime must be applied to the depth of the soil disturbance. Such application will maintain a neutral spoil as oxidation takes place. Because acid spoils and acid drainage water both result from the oxidation of minerals (such as sulfides) located on or near the surface, the stability of surface materials is also a major in-

fluence on acid production. Thus, control of erosion merits special consideration in reducing high concentrations of acids in the spoils. Establishing a quick growing vegetation on the site is probably the best way to control erosion and slow acid production.

Lime can be added to acidic spoils in these forms:

- Ground limestone, or calcium carbonate.
- Burnt lime, or calcium oxide.
- Hydrated lime, or calcium hydroxide.
- Lime residue from sugar-beet processing.

Several considerations are involved in determining what type of lime to use. First, ground limestone is very insoluble in water but quite soluble in an acid. Therefore, if a long-range effect is desired, use agricultural limestone. Ground limestone is most effective when it is ground into various particle sizes and mixed at least 10 inches deep into the spoils. Second, calcium oxide and calcium hydroxide are forms of lime which are very soluble in water. These forms can be used for an immediate effect but would not be long lasting. Burnt lime and hydrated lime may temporarily raise soil pH to values of 8.5-9. After application of these forms of lime, time should be allowed for the pH to stabilize before applying fertilizer.

To determine the amount of lime that must be added to the spoils, the soils scientist must estimate both the amount of acid that currently exists and the amount that will be produced in the mined spoils over a given time. Two methods are used to make this determination:

- The first method is to determine the acidity in the soil-buffer system. Soil-buffer acidity is composed of free hydrogen ions and hydrogen ions that arise from hydration of certain ions, such as aluminum and ferric ions. In agriculture, lime requirements are generally based on the buffering capacity of a soil.
- The second method takes into consideration the oxidation of pyrites—metallic sulfides. This aspect of acid production is particularly relevant to heavy metal spoils because most of the acid found on these sites is produced by this phenomenon.

The rate of oxidation of pyritic material is related to its form and to the particle size of the sulfide material in which it is contained; the finer the material, the more rapid the oxidation. Thus, determining the extent of the acid problem involves concentrating on the material th will contribute to sulfuric-acid productio namely, the small clay-size and fine-sand t clay-size particles—rather than the lar material.

By measuring the sulfide or reduced sul content of these fine materials and the fract of the large material with potential for be weathered down to that size, one can arrive at estimation of oxidation rates and the amo of lime that will be required over time neutralize the acid as it forms. The mic biological activity in the spoil should also considered because oxidation is significant accelerated by microbiological action.

As a specific example, on the Blackbir copper-cobalt mine in Idaho, the buffer l requirement in the spoil material was estima at about 2 tons/acre. But when the sul oxidation in the existing small particulate ma and the material which might be weathered small size over about 20 years time were m ured, the lime requirement increased to average of 20 tons/acre/surface ft of soil de Because lime materials, in particular calc carbonate, do not readily move up and d in the spoil, they must be applied to the dep to be treated. In the example at the Blackb if the soils scientist wanted to treat 2 f surface spoils, he would have applied 40 to the acre rather than 20 tons.

It is estimated that this treatment will las least 10 years, and during this time, na regeneration of native plants should take pl For example, lodgepole pine will replace grasses previously used to stabilize the sp the physical and chemical characteristics of spoils will improve, and acid production decrease as less surface is exposed to oxida and oxygen concentrations in the root zon reduced.

In addition to correcting a low pH, lime wi

- Improve the physical condition of the sp
- Add calcium to the spoil.
- Accelerate decomposition of organic ma providing for release of nitrogen.
- Increase fertilizer efficiency.
- Increase nutrient availability.
- Decrease toxicity of aluminum and ions.

Exception: In rare cases, usually on aba

doned sites when the source producing the acid cannot be determined, it may not be feasible to neutralize the site chemically. Isolating the area may be the only effective treatment. This might include eliminating all possible water from the site, to prevent more acid production, and capping the area with rock. Capping will reduce surface erosion from both wind and water. Further attempts at revegetation may have to be dismissed in these cases; however, a well-planned operation should not leave such a site.

How are alkaline spoils treated?

Choosing salt-tolerant plant species and applying various physical treatments are effective. Chemical amendments are generally reserved for sodic spoils.

Discussion:

Salt-tolerant species, especially various types of grasses, should be identified and considered for revegetation.

Physical treatments for salt-affected spoils include leaching excess soluble salts through irrigation and adding good quality topsoil and organic matter to the spoils to improve spoil aggregation and structure and to increase the fertility of the spoils. Mulching to aid seedling establishment and seeding only when the spoils are well supplied with water are also recommended. Deep tillage should be avoided in high water-table areas or areas where it may cause salt movement up toward the surface. Disking or subsoiling to improve soil structure and aggregation is a viable method elsewhere.

If physical treatments do not alleviate a sodic problem, chemical treatments can be applied. The two most often used chemical amendment types are:

1. Soluble calcium salts. Calcium chloride and calcium sulfate, also known as gypsum.
2. Acids or acid-formers. Sulfur, sulfuric acid, iron sulfate, aluminum sulfate, and lime sulfur.

Soluble calcium salts may be used universally on sodic spoils; these salts replace sodium ions with calcium ions and increase permeability. Calcium chloride is more soluble than gypsum and has a more immediate effect; gypsum is less soluble and less expensive.

Sulfur and sulfuric acid are useful to treat limey spoils. Acids added to spoils containing no alkaline earth carbonates may make the spoils excessively acidic, however. Rely on spoils analysis for specific types and amounts of amendments to use.

> Exception: If a sodium problem exists on a site that has no drainage, leaching may not occur and the treatments prescribed for sodic spoils may not be effective.

Additional Information:

For more information on treating sodic soils with gypsum, a summary of a series of studies performed by Bio-Search and Development Co. for the Old West Regional Commission is provided in this chapter.

How are toxic element problems identified and treated?

Poor growth at very low pH may not be due to excessive hydrogen-ion concentrations, but to an excess and toxicity of iron and aluminum, which are very soluble at such acidity levels, and to the lack of phosphorus, which is insoluble under such conditions. Through testing, the soils scientist must determine if toxic elements are present in amounts that will adversely affect plant growth or the food chain. Treatments are essentially the same as those applied to acid spoils.

Discussion:

As noted before, some plant species have a metal tolerance, and these plants should be identified and used when a seed or plant source is available. If, however, the spoils are identified as toxic to plants (for example, the spoils have a high concentration of aluminum or copper), the pH must be controlled on these spoils so that the toxic metals do not go into solution and become taken up by the plants. Potential toxicity to animals grazing plants containing metals such as boron, molybdenum, and selenium must also be considered.

Why is the addition of organic matter an important treatment?

Organic matter builds and maintains fertile soil from mined spoils. It will improve the spoils both chemically and physically by improving

cation exchange capacity, aggregation, tilth, and water-use efficiency. Organic matter adds essential nutrients through the processes of biological decomposition, oxidation, and reduction.

Discussion:

To accumulate organic matter in spoils, it is necessary to produce high levels of biomass. This is done, first, through careful site prepa[ra]tion. For example, it has been shown that r[ip]ping increases biomass production (table 1[2]). Chemical fertilization is also necessary to [g]ood plant growth and deep roots. Deep root[ing] tends to improve spoil structure, aggregati[on], and water movement through the spoils. [When] these plants die, they contribute an apprecia[ble]

Table 12. — *Effects of ripping on biomass production*[1]

	In ripping marks	Between ripping marks
Shoot biomass	4,000 lb/acre surface biomass	2,000 lb/acre surface bio[mass]
Root biomass	20,000 lb/acre root biomass	10,000 lb/acre root bio[mass]

[1]Information supplied by B. Z. Richardson

TREATING SODIC SOILS WITH GYPSUM

A series of studies performed by Bio-Search and Development Company for Old West Regional Commission has provided some useful principles in treating sodic soils with gypsum:

1. The ammonical radicals (NH_4) of ammonium nitrate and ammonium sulfate fertilizers are superior to the calcium (Ca) cation of gypsum ($CaSO_4$) in removing sodium (Na) from sodic soils. Anhydrous ammonia (NH_3) or urea would not be suitable substitutes, however, due largely to lack of anions in leaching of the sodium.

2. Maximum amendment activity resulted from combinations of gypsum, ammonical fertilizers and calcium chloride ($CaCl_2 \cdot 2H_2O$) of the folowing ratio:

Gypsum	80%
$(NH_4)\ 2SO_4$	10%
$CaCl_2 \cdot 2H_2O$	10%

Such a combination is more than twice as effective as gypsum alone. Early results also indicate that the above combination is superior to gypsum alone in preventing upward migration of sodium from mine spoils into replaced topsoils.

3. Scrubber waste from power plants using limestone ($CaCO_3$) as the scrubber agent is almost as active as gypsum in treating sodic spoils. Although composition of scrubber waste will naturally vary from plant to plant, it is usually composed mainly of $CaCO_3$, $CaSO_4$ and $CaSO_3$. Addition of 10 percent ammonical fertilizers results in good amendment properties and essentially doubles the degree of activity compared with scrubber wast[e] alone.

4. A "Filter Rate" analysis, as developed b[y] Bio-Search, was the single most consistent indic[a]tor of amendment action. SAR (sodium adsor[p]tion ratio), calcium, sodium, or the Ca/Na rati[o] are inadequate measurements of amendme[n]t activity. "Filter Rate" was also the only one of th[e] above indicators that was significantly correlate[d] with yield of the harvested crops in field ar[d] greenhouse studies.

The "Filter Rate" test is performed as follow[s]: Soil is ground to pass a 2 mm sieve. Air dried 0.5[3] lb lots are weighed, placed in 2-quart plastic co[n]tainers, and the appropriate amendment-dosa[g]e is added, followed by deionized water to give th[e] soil:water ratio desired (generally 1:3). The res[ul]tant slurry is mixed until homogeneous ar[d] allowed to sit overnight (20 hr). The next mor[n]ing the slurry is transferred to Buchner funnels ar[d] the extract of filtrate collected. The amount [of] filtrate collected in 100 ml graduates (witho[ut] suction) after 2 hr is recorded and reported [as] "filtration rate." The total amount of filtra[te] collected is also recorded. Time is a big factor [in] collecting total filtrate—the higher amendme[nt] dosages increase soil permeability, and filtrati[on] may be complete in 2 to 3 hr, whereas the u[n]treated controls may require 12 to 20 hr of f[il]tration time. Presumably, this method wou[ld] relate to infiltration rate as measured by mo[re] conventional means.

mount of organic matter to the spoils. The urface residues act as a mulch, aiding in water nfiltration and erosion control as decomposiion takes place. Root residues usually deompose at a slower rate and thus serve as a ontinuous reservoir of polysaccharides for ggregate stabilization and a reservoir of nutrints for recycling to new plants.

Micro-organisms in the spoil convert these lant residues to elemental nutrients, which timulates growth in both micro-organisms and lants. Thus, a constant source of energy is supplied by growing plants to soil micro-organisms, hich in turn makes nutrients available to lants. This explains why, once organic matter established in the spoil material, supplements f inorganic nutrients are rarely needed. Early in e process, however, nitrogen fertilization may e necessary because it is the nutrient most eeded by micro-organisms in decomposing rganic matter. Nitrogen is also the most mobile f the major nutrients and can be readily lost y leaching from rain or snow melt. Microrganisms may consume more than 20 lb of itrogen/ton of grass in the decomposition of at grass. Twenty pounds or more of nitrogen/ on of mulch may also be consumed or "tied o" by microbial metabolism as the mulch ecomposes. Thus when organic mulches are sed, nitrogen fertilization must be increased.

PHYSICAL PROBLEMS/TREATMENTS

Physical problems in the spoils include extremes in texture, lack of or unfavorable structure, and lack of organic matter. Physical treatments can include mulching, mechanical/ surface manipulation, and leaching. Counteracting the adverse effects of poor texture and structure by mixing spoils and the addition of organic matter are important because of their influence on infiltration, permeability, drainage, moisture storage, aeration, plasticity, compaction, ease of root penetration, crusting, and retention of plant nutrients. The importance of organic matter has been discussed in some detail earlier in this chapter. Figures 23-31 illustrate one successful site-preparation sequence.

What is meant by texture and structure and why are they important?

Texture is the relative proportions by weight of sand, silt, and clay. Structure is the aggregation of primary particles of sand, silt, and clay into compound parts or clusters. The correct texture and structure of spoils are important in providing a suitable plant-growing medium.

Discussion:

Structure is not as important a characteristic

Figures 23-31. Site preparation sequence used at Decker Coal Mine, Decker, Mont. (Dwight Layton, Decker Coal Mine)

Figure 23. Ripping spoils.

Figure 24. Laying down topsoil.

Figure 25. Ripping topsoil.

Figure 26. Disking.

Figure 27. Fertilizing.

Figure 28. Harrowing.

Figure 29. Seeding.

Figure 30. Hydromulching.

Figure 31. Results.

as is texture, but it does influence the effects of texture in terms of moisture/aeration relations, available plant nutrients, micro-organism distribution, moisture infiltration, and permeability.

Texture is important because this property influences permeability and the amount of water available to plants. Texture must be considered early in the rehabilitation process because it is a permanent condition and influences all subsequent reclamation activities on the site.

Clays, for example, have a relatively high water-retention capacity, but their permeability is low and, if they also contain appreciable quantities of exchangeable sodium, the material becomes essentially impermeable. By comparison, sand has a high permeability but low water-retention capacity, and this can lead to a droughty condition.

How can a suitable texture be achieved?

Placing medium-textured material—not extremely high in either clay or sand—in the plant-growth zone is ideal. But if these kinds of materials are not available, mixing prescribed amounts of favorable soil textural types can artificially produce the desired texture. The addition of organic matter and proper tillage operations can counteract the adverse effects of poor texture by improving moisture/aeration relationships.

Discussion:

When it is not possible to replace topsoil on the disturbed site and when a suitable substitute from the overburden strata is not available, the return material must be treated sufficiently to support plant growth. Treatments to reduce compaction are usually necessary. For example, ripping and harrowing the spoils during seedbed preparation will reduce compaction and increase the infiltration capacity of the spoil. Contour planting, fertilizing, mulching, and cultivating will aid in plant establishment, thus encouraging the production of organic matter. As discussed earlier, organic matter plays a crucial role in improving the physical and chemical characteristics of soils and spoils.

In a greenhouse study on high-sodic, bentonite spoils, vermiculite and sawdust were effective amendments. They reduced cracking in the spoils, and the sawdust added organic matter at the same time. It appears that these materials act as a binder and limit the stretching cha teristics of the spoils.

BIOLOGICAL PROBLEMS/TREATMENT

Because ultimate reclamation goals air returning the mined site to some type of ductive use, the ability of the site to sus life without endangering its stability become important aspect of rehabilitation. In addit many organisms, especially micro-organisms essential to the soil forming process. macro- and micro-organisms are included ir discussion.

What site conditions are necessary to sup macro-organisms?

Different animals require different type habitat. For example, animals respond in ferent ways to all these soil conditions: e tion, geomorphology, slope aspect and s steepness, soil temperature and moisture, r ness, soil pH, conductivity, macro- and mi nutrients, and compaction. Thus the typ animal life desired will influence how the should be managed.

Discussion:

Several general examples of preferred hab of various animals from a soils perspe follow:

- Deer. Deer prefer north-facing slopes i summer, south-facing slopes in the winter toxicity is important—for example, high centrations of copper in plants can be tox deer. Deer often depend on salts found in and soils on valley bottoms.
- Cattle. For uniform utilization of the slopes should be less than 20 percent.
- Burrowing animals. Burrowing animals soil texture on burrow mounds to become They will reduce compaction by their bu ing. In studying pocket mice, a type of bu ing animal, it was found that they inhabi densely vegetated sites in greater numbers they inhabit densely vegetated areas. Phosp and sulfur levels increased in soils inhabit these animals; calcium and magnesium decreased.
- Birds. With the exception of waterfo plant cover increases, birds observed on

s generally decrease in numbers. Hawks and s will inhabit rock outcroppings.

Bobcats, rabbits, snakes, lizards. These anis prefer rocky areas.

it problems can occur with the introduction nacro-organisms onto a mined site?

n some cases, the introduction of macronisms onto the site will lessen the stability he soil or seriously deplete the vegetation.

ussion:

ome areas may have such critical characters as slope compactability that animals uld be restricted or specifically managed to ent further damage or deterioration of a aimed site.

'ith intense grazing, soil moisture will dese, and soil temperature and compaction will ease. Burrowing animals may bring harmful tances, such as radioactive, toxic, or salt erials, to the surface.

n addition, if the site is managed for species prefer bare soils, erosion and sedimentation olems may occur. In general, managing a area to accommodate such animals should considered only if they are an endangered ies.

is the lack of micro-organisms in the spoils oblem?

icro-organisms, such as bacteria and fungi, important in the decomposition of biological erials and the formation and improvement of itself. But because most microbial activity urs in the upper layers of soil, mined spoils se surfaces consist of deeper layers of geo material may be void of these organisms.

ussion:

n their roles as decomposers, microgenisms reduce plant litter, which lowers fire ards and perhaps aids in seedling emergence. hey are the major contributors to nutrient ycing, releasing to the environment the nutrits that have been fixed into plants or other iological materials. The formation of soil rganic matter, or the process of humification, is iated primarily by micro-organisms. They so indirectly reduce soil bulk density by imroving aggregation.

Nutrient cycling, especially nitrogen cycling, is a major contribution of micro-organisms. They also make phosphorus available to plants through phosphorus solubilization.

Thus, it is apparent that unless artificial amendments can be added to the reclaimed site indefinitely, the introduction of micro-organisms is essential to allow a natural system of building and maintaining fertile soil to take over.

Will micro-organisms move onto the site through natural processes?

It is generally thought that eventually micro-organisms will naturally reestablish themselves in mined spoils. How long this takes will be influenced by the spoils' properties, including physical and chemical characteristics and water dynamics, how topsoiling and soil storage was handled during mining, the rate of vegetation establishment, and the rate of natural inoculation of spoils.

Discussion:

As the amount of clay in the spoils increases, micro-organisms living in the spoils decrease. Salinity, acidity, and the presence of significant amounts of heavy metals in the spoils may inhibit microbial activity. Thus the chemical and nutrient status of the spoil must be in balance at a favorable level to allow micro-organisms to establish themselves and function properly. In addition, moisture must be sufficient for the organisms to carry out their activities, even though they can survive on much less water than can plants.

The effects of topsoil storage on microbial activity are not completely agreed upon by researchers, but the general indication is that microbial processes are adversely affected by topsoil storage, especially if long term and in deep piles.

How can micro-organisms be reestablished in soils?

Both natural processes and artifical amendments are known to increase microbial activity.

Discussion:

Activities that will increase microbial activity include:

- Replacing the topsoil on the mined spoils.

Replace the topsoil as soon as possible after it is removed. If it must be stockpiled, shallow, wide piles are recommended over narrow, deep ones, because most micro-organisms function best near the soil surface. An advantage of quick replacement of the topsoil is that some of the seeds and plants transported in the topsoil will grow on the new site rather than losing their viability because of long-term storage.

> Exception: If wind erosion is a problem, then shallow storage of topsoiling may result in the loss of this valuable resource. The topsoil surface should be protected in some way from wind erosion, perhaps through mulching or temporary seeding with a fast establishing grass.

• Natural processes, such as dust blowing on the site from other areas, will reinoculate the site. Root penetration into the spoils and the development of a rhizosphere environment are also thought to perpetuate the growth of micro-organisms.

• Correcting the spoils for acid, salt, or trace element problems will provide a spoil condition conducive to microbial activity.

• Adding nutrients necessary to assure microbial activity is important. In particular, micro-organisms need a sufficient amount of carbon, phosphorus, and nitrogen. Sufficient carbon will be obtained through mulching. Sufficient nitrogen and phosphorus will probably be obtained through fertilization amounts required to establish plant growth.

• Inoculating the site with micro-organisms, such as nitrogen-fixing algae and/or bacteria. Mulching will help inoculate spoils with micro-arthropods.

• Collecting surface material from undisturbed sites and placing this material on the mined spoils to introduce micro-organisms.

How does the soils scientist determine if microbial activity on the spoils has returned to a level found on adjacent undisturbed sites?

Laboratory analysis for microbially related soil activity can be used to compare undisturbed sites with rehabilitated areas. This comparison will help determine if postmining microbial activity is comparable to the premining site. Population numbers by species in rehabilitated and undisturbed areas are very time consuming and expensive to determine and are, therefore, not useful for most monitoring programs.

Discussion:

Lab analysis for microbially related soil enzymatic activity includes dehydrogenase, phosphatease, and urease. Biomass indicators include adenasine triphosphate (ATP), viable counts, and direct microscopic counts.

In one study on a salt-affected coal mine it appeared that microbial activities on the mined site returned to levels found on adjacent areas about 3 years after revegetation. Nitrogen-fixing micro-organisms, however, were not as well established as other species, thus indicating that long-term nitrogen fertilization may be necessary. In addition, there was a decrease in microbial activity with the depth of the spoils.

Additional Information:

For more information on treating chemical and physical problems in mine spoils, refer to:

"Handbook on Soils," USDA For. Serv., FSH 2509.15. Washington, D.C. (Amended July 1969.)

Chapter 7
SPOILS SURFACING

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s discussed in chapter 2, premining analysis he soils and overburden predicts if and in t quantity topsoil and subsoil materials ld be stockpiled for later placement on the spoils. This analysis, along with State and ral regulations, also determines whether soil ld be removed in one or two lifts.

fter the mineral is mined, the spoils are ed and analyzed, indicated treatments are ied, and the spoils are surfaced with the kpiled soil. If, prior to mining, the soil was oved in two lifts, the second lift is now ed on the spoils, and the first lift is placed op of the second lift.

o insure immediate and long-term value of spoils surfacing effort, potential problems t be overcome by appropriate treatments ied out during or after spoils surfacing. For nple, if spoils analysis indicated that the tity of the spoils is less than predicted ng premining analysis and that the quantity opsoil stockpiled will not be sufficient to e as a plant-growth medium, additional oil should be obtained from adjacent sites, ssible, and spread on the surface.

e most important problems threatening physical integrity and ability of resurfaced to support plant growth are surface erosion overcompaction of soils and spoils. Upward ation of toxic elements or salts also presents lems in some cases. This chapter will discuss potential problems in more detail.

SURFACE EROSION

vital component of spoils surfacing activity is reducing or preventing surface erosion. Steep, bare, unrevegetated spoils are subject to high rates of erosion by both water and wind (fig. 32). The effect of this is to lessen the stability of the site and, just as important, to remove the valuable topsoil resource that has been surfaced on the mined area. As a result, special efforts to prevent surface erosion are warranted, especially considering that repair of erosion damage is one of the most expensive recurring costs on reclaimed sites. In addition, in some situations, State or Federal laws govern the amount of erosion that is acceptable, and thus the site must be monitored for erosion to satisfy these requirements.

What factors increase erosion by water and wind?

Slope steepness, slope length, drainage provided, control structures, lack of vegetation on slopes, and the type of spoils and soils material on the site will affect the amount of wind and water erosion that will occur.

Discussion:

Research has demonstrated that soil losses from erosion on mined sites can be significant. For example, a 1-year-old, newly reseeded mine dump, which was essentially bare of vegetation, was measured for the amount of erosion that occurred from October to the following July. On a south-facing slope of 48 percent, with a slope length of 1,100 ft, the measured loss was 69 tons/acre. Another example: On a north-facing slope with a steepness of 23 percent and a slope length of 330 ft, the loss was 135 tons/acre. Erosion in both examples was mainly due to water.

Erosion from wind can also be significant. For example, in a Western phosphate field, the production of fugitive dust has been estimated at 1/2 lb/ton of material mined. In 1978, the

production of fugitive dust was estimated at 5,250 tons.

The controlling effect of vegetation on erosion was demonstrated when the areas in the preceding examples were measured after the establishment of vegetative cover (fig. 33). In general, after the second or third year of plant growth, reduction in erosion was on the order of about 90 percent. In this particular study, ground cover was estimated at about 70 percent.

In the Eastern United States it has been found that about half of all soil losses occur in the first 6 months after mining. Thus, it appears that erosion rates are highest during dump construction and during the time from final shaping to the establishment of a protective vegetative cover—in the West, typically 1 year.

Soils that contain finer particles and are less compacted obviously will be subject to heavier erosion losses than coarse-textured or compacted material. It has also been found topsoil is generally a little more stable than spoil material because of aggregation.

What treatments will reduce erosion by wind and water?

Mulching, surface manipulation, and pr timing of topsoil placement, followed immediate establishment of vegetation, reduce erosion rates on mined sites.

Discussion:

Mulching is probably one of the economical and widely applied method controlling erosion because it reduces the im of raindrops, overland water flow, and (fig. 34).

Several kinds of mulches are effective, straw is probably the most economical readily available mulch (fig. 35).

Figure 32. Eroding, ungraded spoils are contrasted with graded revegetated spoils at a coal mine site

veral techniques of surface manipulation ffective:

Flatter or shorter slopes will aid in erosion rol. Also note, however, that State or ral regulations may dictate slope steepness ength.

Sediment basins will help to collect material ing off the site.

f immediate revegetation is not possible, nent basins constructed at the toe of new dumps may be useful in collecting eroding rial—if these basins are correctly designed.

hallow furrowing on the contour will cut on erosion losses.

itting and gouging will both control erosion act as moisture collectors. Because of their functions, pitting and gouging are especially ıl in dry areas and those areas where vegeta-is dependent on snowmelt for moisture. Pits gouges differ from each other only in size. Pits, also called basins, are approximately 2-1/2 ft deep and may be 8 ft wide by 15 ft long. Gouges, on the other hand, are a series of small pits about 3-6 inches deep, 18 inches wide and 2 ft long. A number of these depressions are made on the site. Pits are generally used on steeper slopes (3:1, for example); gouging is done on less steep slopes.

A variation of gouging is accomplished by using a land imprinting machine. Although the land imprinter was not specifically developed for mined lands, it has been used on bare sites in Arizona to imprint the surface, which, in turn, catches water runoff and holds it in place, rather than allowing it to run down slopes and cause erosion.

• Buffer stripping during mining can also be encouraged, although this is usually not practical from a mining standpoint.

It has been noted that, because topsoil is an

Figure 33. Establishing vegetation on steep slopes aids erosion control. The above photo shows an erosion control study plot 3 years after vegetation was planted.

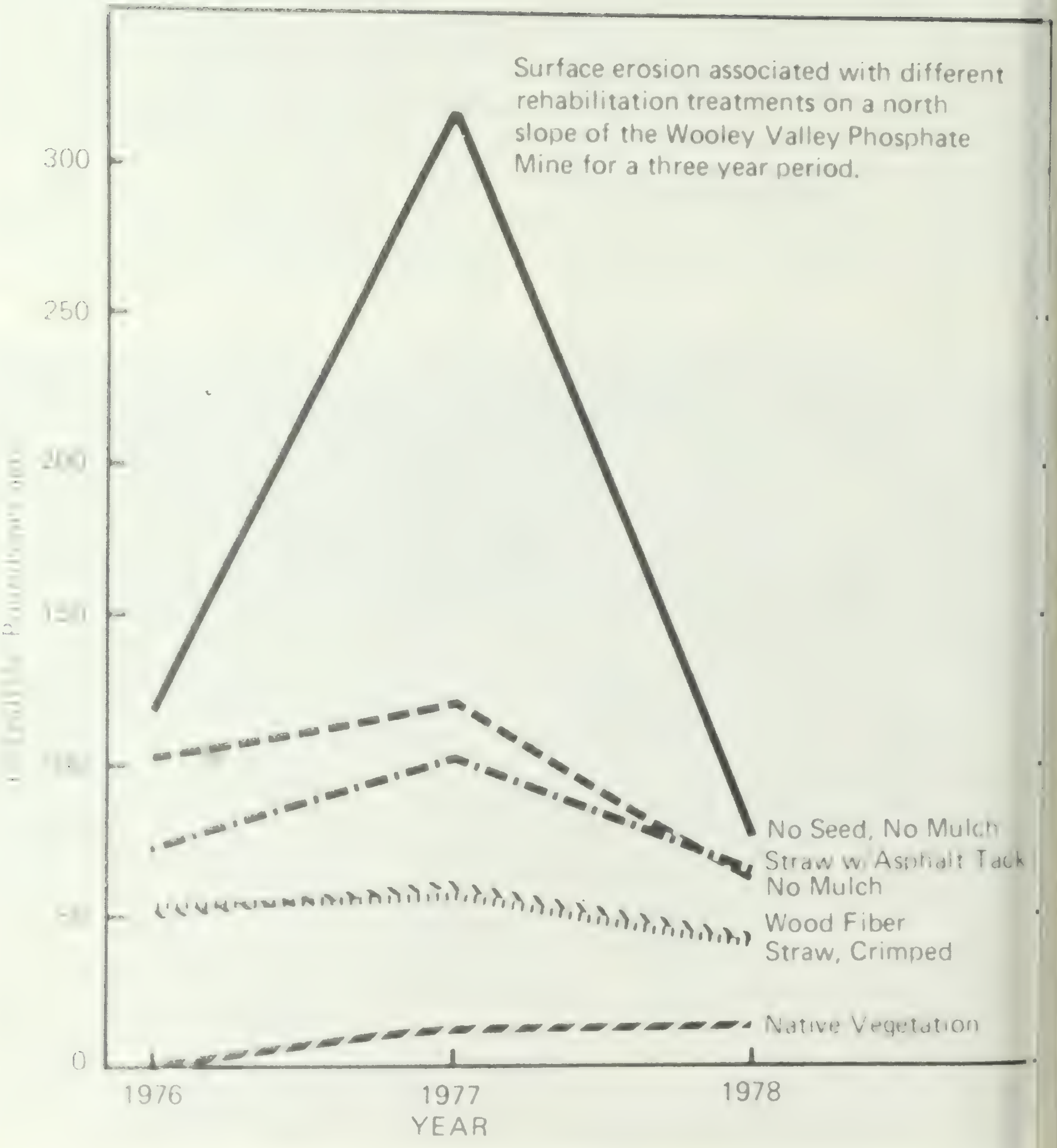

Figure 34. Mulching a revegetated site will reduce soil losses due to surface erosion.

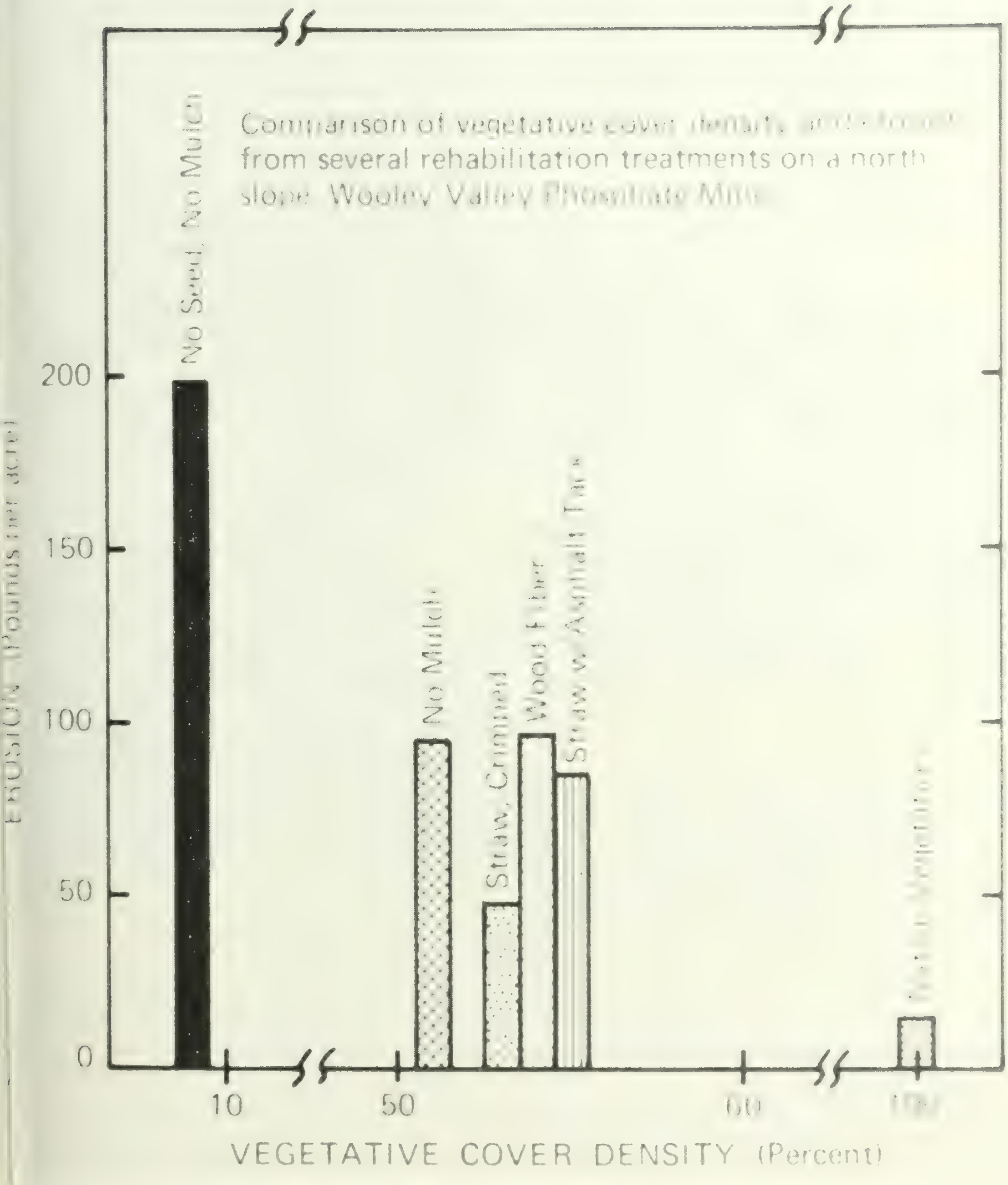

Figure 35. Straw mulch aids in both reducing surface erosion and increasing vegetative cover density.

extremely valuable resource, it should be replaced on the site immediately prior to the best growing season; i.e., just before expected precipitation. In that way, planting can immediately follow topsoil replacement, and a vegetative cover can be quickly established on the site to protect the topsoil.

In those cases where it is feared that excessive erosion will occur during the time it takes for seeds to germinate and establish themselves, the use of bare-root, container-grown, or other transplant stock that will quickly take root and act in erosion control should be considered.

OVERCOMPACTION AND RELATED PROBLEMS

The heavy machinery used to regrade and spread spoils often leaves the material so compacted that root penetration is reduced or blocked. Ripping the spoils can ameliorate overcompaction problems. Tilling the spread topsoil prior to seeding can overcome compaction of the upper soil.

What other problems related to the stripping and respreading process are ameliorated by tillage?

The condition of the smooth, hard interfaces that are often created between the spoil and overspread soil, and the layers of distinctly different subsoil and/or topsoil materials can be improved by tillage.

Discussion:

Topsoil or subsoil spread over a smooth, hard, spoil surface may be subject to slippage or slumping if the hydraulic conductivity of the spoil is sufficiently reduced and if the site is sufficiently sloped. Ripping or deep tillage of the spoil surface during regrading should ameliorate this situation.

What factors are involved in overcompaction, and how can compaction be measured?

The weight, type, and traffic pattern of machinery are, of course, factors. In general, the higher the water content and the finer the texture of the material, the greater will be the potential for overcompaction. Several types of analyses can be used to measure compaction and should be chosen based on the dryness or ness of the spoils.

Discussion:

For dry materials, bulk density measuren will give an approximate indication of over paction, provided textural data on the mat are also available. Bulk density measuren can also be taken on wetter materials. materials either partially or fully saturatec of a recording field penetrometer will g good indication of compaction levels.

Field penetrometers indicate "penetro soil strength," a measure that researc linked quite well to the resistance plant encounter as they penetrate the soil. This of measurement will be especially useful t or second lift soil characterization wher gravel or stone content is low. Wetting a area of the reclaimed soil and allowing drain to field capacity before making trometer measurements is the best proc Penetrometer soil strength is most logical terpreted by reference to some standar water content.

TOXIC ELEMENTS AND SALT MIGRATIONS

Toxic elements can migrate from taili spoils into the respread topsoil, rende phytotoxic in the extreme case or result plant products that are deleterious to anin humans when consumed. Upward salt tions are a special problem where sodic are found. Physical properties—for ex tilth and hydraulic conductivity—of over soil deteriorate as a result of such salt tions.

How may toxic-element and salt migrati abated?

In suitable circumstances, spreading a l gravel or sandstone between the spoils a soil may prevent toxic elements from e the plant-rooting zone. Using such coa tured materials between the spoil, which exhibits a low hydraulic conductivity, a soils material will reduce diffusive sal Putting gravel or sandstone on the top o tailings material will break up water flo

ries salts or toxic elements upward as soil poration proceeds.*

cussion:

Generally, the use of these materials is less tly than bringing in additional topsoil. The s scientist should consult a civil engineer, vever, to insure that this interlayer of terial will not set up a slippage face, or create one where a great deal of lateral water movent will occur.

w are salt migrations predicted?

Figure 36 shows a general model for preing salt migrations in reclaimed soils. Currently, however, this information is worked out only for research usage and is not yet user-oriented.

Discussion:

In the model shown in figure 36, plant growth is not predicted, but root uptake must be approximately known. This limits the applicability of the model to areas where this knowledge is available. Unsaturated hydraulic conductivity and water-retention capacity of soils and spoils are the key information needed for this type of calculation. Unsaturated hydraulic conductivity measurements are generally limited to research use, however.

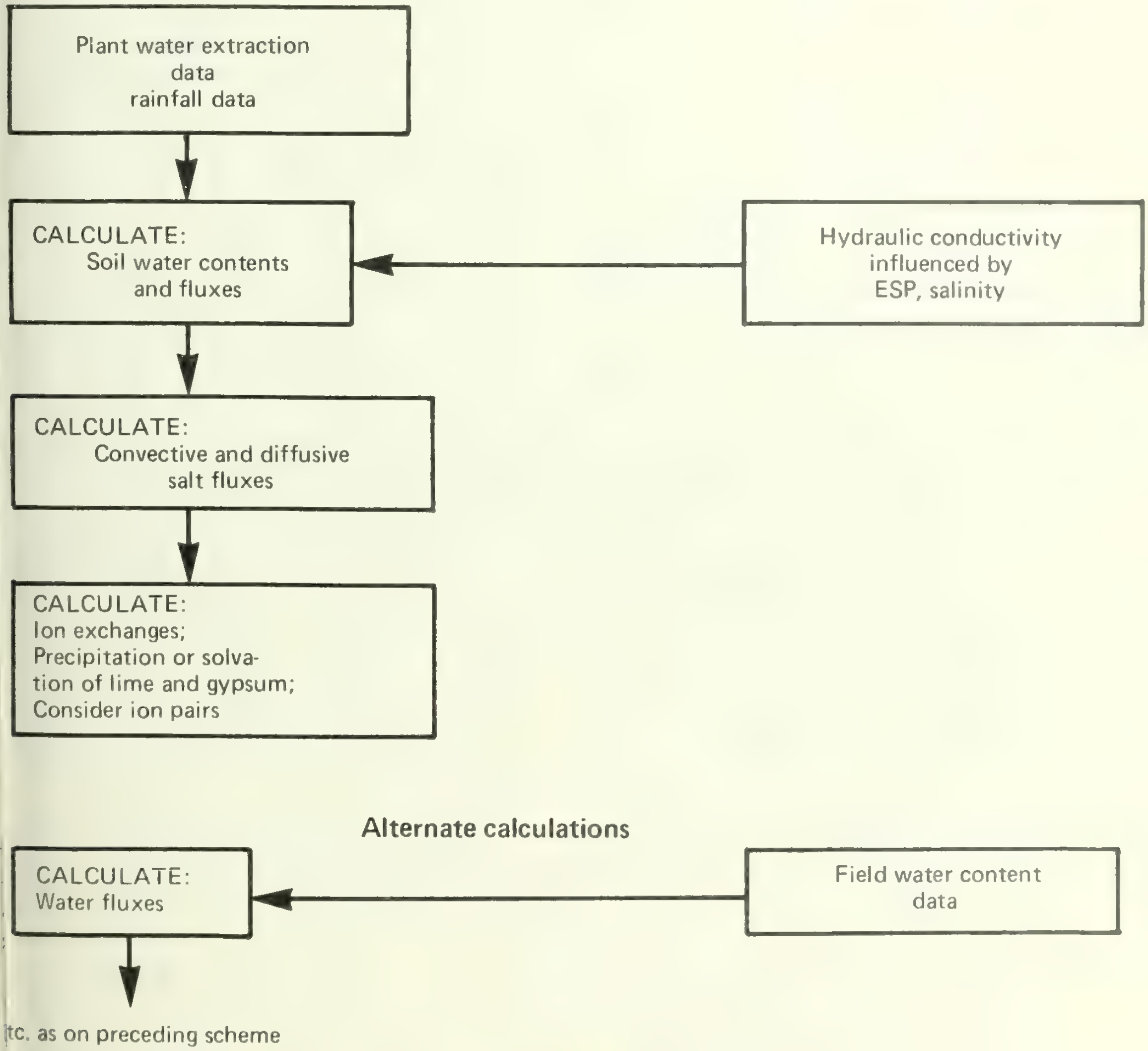

Figure 36. Outline for predicting salt migration in reclaimed soils.

Chapter 8
MONITORING AND RETREATMENT

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jor Contributors: Earl F. Aldon, Richard L. dder

Once reclamation work is completed, a period monitoring follows, during which the success the reclamation program is evaluated and, if essary, the site is retreated to correct probs that have surfaced. The object of this postning monitoring is to assess whether the ning operator has fulfilled his obligation to quately reclaim the site and thus can be resed from his performance bond. Input from a s scientist will be essential in making these erminations.

Because intensive reclamation of western elands is relatively recent, postmining moning and performance standards remain vague general. In some cases, such as in coal ning, there are some legal requirements, but se, again, are quite broad. For example, the ulations require that a postmining landnagement plan be drawn up, outlining the use uses to which the land will be put following ing and reclamation, with a discussion of sible alternative uses and their relationship xisting land-management policies. The plans t also include an explanation of how the mining land use will be achieved, including agement and materials required.

n light of these generalities, the land manager have to rely on available scientific knowld and his own judgment when setting criteria releasing the mining operator's performance d. These standards should be understood and ed upon by both the land manager and the ing operator prior to mining and should be ined in the operating plan; however, an alance for variances as unexpected circumces occur is also advisable. The standards ld include estimated monitoring costs as e as needed personnel.

During the establishment of postmining goals, the land manager and his interdisciplinary team must keep accurate records on the condition of the site prior to mining; the reclamation work done; the potential of the site; and the postmining condition of the site. This process should be recorded carefully in case any part of the mining or reclamation procedure is challenged.

MONITORING

What should the soils scientist monitor during postmining?

Primarily, the soils scientist will monitor and evaluate the plant-soil response to reclamation treatments. He may also be asked to provide information on precipitation and weather variables following reclamation, sediment load, the effect of the area on ground-water quality, salt movement in the soil, erosion rates, and the effects of management practices used on the soil.

Discussion:

A sampling program should be undertaken in order to monitor plant-soil responses to reclamation treatments. The soils scientist will have to determine what sampling intensity to use based on his judgment of the condition of the site, but some research indicates that 1 percent of the total mined area should be sampled.

During sampling, areas where reclamation may have been less successful should be focused on (fig. 37). These include:

- Slopes, in particular, south- and west-facing slopes
- Old road locations
- Former equipment storage sites
- High runoff sites
- Areas with high clay content, or concentrations of sodium or other salts.

What tests should be run on the samples and how should they be interpreted?

The type of testing on the site depends on regulations governing postmining testing, and what problems were identified on the site during mining. The tests should be interpreted against the criteria for reclamation success set up in the operating plan. This comparison will indicate how much the final outcome deviated from the plan, and if this deviation can be tolerated.

Discussion:

If problem areas surfaced during premining soils and overburden analysis or spoils analysis, such conditions should be retested during postmining monitoring to determine if any further retreatment is necessary. In addition, if the soils scientist observed any additional problems on the site, these should be analyzed further.

Interpretations of the tests should be made against the performance standards for the site. Obviously, these can vary, depending on regulations governing the mine operations and the climatic conditions of the site. For example, in some parts of the country, a 70-percent vegetation cover would not be judged adequate; whereas in low rainfall regions, a 20-percent cover is considered adequate. In other wo different levels of "non-reclamation" tolerated.

RETREATMENT

Based on field observations and the result the sampling and testing program during mo toring of the site, the soils scientist and l manager may determine that some retreatm is required before the performance bond car released. Retreatments can include:

- Chemical treatments. Follow-up fertilizat or liming.
- Physical treatments. Erosion protection mulching, fencing.
- Biological treatments. Species manipulat both of plant and animal organisms.

What refertilization treatments may be ne sary?

Based on on-site observations and soils an sis, the site may need to be refertilized various soil nutrients, in particular, nitrogen phosphorus. Refertilization is important for reasons: (1) to support permanent vegetatio

Figure 37. Harsh sites, such as these bentonite spoil ponds, will require special reclamation emphasis and monitoring during postmining.

ite, which will protect the site from erosion, (2) to increase the biomass growing in and ne soil.

ussion:

addition to soils analysis, nutrient deficien- can also be observed in plants. Nitrogen iencies are indicated by yellowish-colored s; slow or dwarfed growth; and drying up or g of leaves, which starts at the bottom of dy plants and proceeds upward or, in es, starts at the tip of the bottom leaves and eeds downward.

osphorus deficiencies are noted by purplish s, stems, and branches; slow growth and rity; and small slender plants. Low yields ains and fruits or no seedheads in grass also ate phosphorus deficiencies. Potassium defi- ies can be observed in plants showing a ling, spotting, streaking, and curling of s, starting on the lower stems; lower leaves re scorched or burned on margins and tips; remature loss of leaves.

tes for retreating with nitrogen depend on severity of the nitrogen deficiency as red from soils analysis, but in general, 40- of nitrogen/acre are recommended. Addi- nitrogen will be required if organic dments are added at the same time.

s important to note that nitrogen deficien- an be a long-term problem and may require ed applications of fertilizer. In some cases, te must be refertilized every 2 years for the few years, then every 3 or 4 years for l years thereafter. Unfortunately, current ch does not indicate in what time span en refertilization will no longer be neces- Thus, the cost of refertilization over a long must be balanced against the cost of the m. If costs are prohibitive, plants adapted w ntirogen, such as woody species, are mended. This approach is particularly in certain dry climates where fertilizer ot stay in the soil long enough to have a effect. Another technique is to supply oil with more organic matter because c matter aids in holding available nutri- Encouragement of legumes or free-living, n-fixing microbes reduces or eliminates d for long-term refertilization.

Rearding phosphorus, 50 lb/acre of triple- hosphate are sometimes recommended, but on moderately sodic soils, where the SAR is about 12, this amount may have to be increased to about 75 lb/acre. Phosphorus refertilization is minimal—one repeat application is generally sufficient on soils where tests indicate a phosphorus deficiency.

When is repeat liming necessary?

If postmining soils tests indicate an acid problem, a repeat application of lime may be necessary.

Discussion:

Hot spots can sometimes be found on the reclaimed surface after mining, usually caused by an acid reaction in the materials. In the case of coal, regulations state that any material that might spontaneously catch fire be buried by at least 4 ft of material. If fire combustion is not a problem, reliming with calcium carbonate to meet the total lime requirement as determined by testing should provide protection against reoccurrence of acid conditions (see chapter 6).

Additional Information:

For more information on liming, refer to chapter 6.

What physical retreatments should be considered?

Physical retreatments of the site might include repairs to badly eroding areas, remulching on problem areas, fencing, and water and range improvements.

Discussion:

It is recommended that whenever possible, heavy equipment be kept off the site and erosion repairs done by hand, especially if the area involved is relatively small.

Mulching is one way to minimize physical problems, such as gully or sheet erosion, if the size of the gullying system or the sheet erosion is not too large. If a large area is involved, more extensive treatments might be required. Such large gullies are indicators of poor surface hydrology designs in reformed land; these should be corrected before revegetation begins. The mulch should be crimped into the soil.

Fencing (fig. 38) and water and range im-

Figure 38. Fencing may be necessary to protect fragile areas until vegetation is established and soils are stable.

provements are necessary in order to insure the plant and soil stability of the area during the postmining period. For example, because the vegetation on a reclaimed site is often more palatable than vegetation growing on adjacent areas, it may have to be protected from livestock and wildlife until it is firmly established. In addition, roads built during the mining activity will make the area more accessible to human traffic, and thus fencing the area from such traffic compaction may be necessary in order to protect the site.

Additional Information:

For more information on making hand repairs of small gully systems, blowouts, or problem areas, refer to:

"Watershed Structural Measures Handbook," USDA, For. Serv., Handb. 2534. December 1958.

"Land Treatment Measures Handbook," USDA, For. Serv., Handb. 2533. February 1959.

What biological retreatments should be considered?

Biological retreatments might include species manipulation to improve the soil's characteristics, addition of mycorrhizal spores and micro-organisms to the soil, and protection of the [illegible] from macro-organisms.

Discussion

The following treatments are only a few [illegible] in which vegetation can be used to improve [illegible] quality:

- Use of green manure. For exampl[illegible] Russian thistle has invaded the area, it ca[illegible] used as a green manure crop if it is turned u[illegible] while still small, and the area reseeded [illegible] another species. This is useful in reseeding [illegible] repairing small (2-5 acre) areas.
- Interseeding to provide more ground [illegible] and increase species diversity. If possible, [illegible] recommended that hand-held or small mac[illegible] operated equipment be used to avoid distu[illegible] the site as much as possible.

Before mycorrhizal spores and mi[illegible] organisms are added to the soil, the site sh[illegible] be tested to find whether or not mycor[illegible] spores and micro-organisms already exist o[illegible] site. For example, mycorrhizal spores are [illegible] intolerant of prolonged dry conditions or [illegible] longed very wet conditions, and if the to[illegible] had been stockpiled for a long time, [illegible] mycorrhizal species may have been lost i[illegible] soil mass. If these organisms were sample[illegible] in premining stages, the soils scientist ca[illegible] this figure to make a postmining compa[illegible] Then, if testing indicates a problem, it is i[illegible] tant to reinoculate the site using viable [illegible] material. Likewise, other micro-organisms [illegible] as termites, play a role in the refertili[illegible] process but may have disappeared during m[illegible] and resurfacing activities.

Some macro-organisms are harmful to th[illegible] and may have to be removed. For exa[illegible] small rodents or ants may cause problem[illegible] spoils where toxic materials are buried belo[illegible] surface. These burrowing animals may brin[illegible] material up to the surface in the course o[illegible] digging. They may also destroy some [illegible] vegetation.

Additional Information:

Refer to the "User Guide to Veget[illegible] (USDA, For. Serv. Gen. Tech. Rep. INT-6[illegible] more information on topics covered i[illegible] chapter, including reinoculation of [illegible] organisms, refertilization, fencing, and [illegible] seeding.

APPENDIX A

GLOSSARY

c soil: A soil containing a preponderance ydrogen ions, often occurring when sulfide rals are oxidized. Values below pH 7 indi-n acidic soil.

rption: Adsorption is the increased con-ation of molecules or ions at a surface, ding exchangeable cations and anions on articles.

ine soil: Soil with a pH 7, and which con- excessive concentrations of soluble "—ions of calcium, magnesium, potassium, e, chloride, nitrate, boron, and others. see: Sodic soil.)

er: A geologic formation or structure that nits water in sufficient quantity to supply eeds for a water development, such as a The term "water-bearing" is sometimes synonymously with "aquifer" when a m furnishes water for a specific use. ers are usually saturated sands, gravel, red rock, or cavernous and vesicular rock.

ne data: Data gathered prior to mining e purpose of outlining conditions existing undisturbed site. Reclamation success is red against baseline data.

i exchange: Cation exchange is the inter- of a cation in solution with another on a surface of active material.

e A sample of the subsurface and geologic als obtained by vertical drilling. The cores ed to evaluate the quality of a mineral; so show the type of overburden material ng the ore.

ic area: An area that should not be dis-e (i.e., mined) because it is deemed ely difficult or impossible to reclaim.

ped soil: Dispersed soil is soil which has r no resistance to the slaking action of Also, it is soil in which the clay readily ollodial suspensions.

Dump: Also called fill, backfill, or storage site, a dump is an area where overburden is piled during the mining process, either temporarily or permanently.

Electrical conductivity (EC): A measurement of salinity. A soil is considered saline if the EC of a saturated extract is 4 mmho/cm. (U.S. Salinity Lab Staff)

Environmental Assessment (EA) (Replaced the EAR): An analysis of all actions and their predictable short- and long-term environmental effects, which include physical, biological, economic, and social factors and their interactions. Also, a concise public document required by the regulations for implementing the procedural requirements of the National Environmental Policy Act of 1969 (NEPA).

Environmental Impact Statement (EIS): A document prepared by a Federal agency in which anticipated environmental effects of a planned course of action or development are evaluated, as prescribed by the National Environmental Policy Act of 1969 (NEPA).

Erosion: The group of processes whereby earthy or rock material is worn away, loosened, or dissolved and removed from any part of the earth's surface. It includes the processes of weathering, solution, corrosion, and transportation. Erosion is often classified by the eroding agent (wind, water, wave, or raindrop erosion) and/or by the appearance of the erosion (sheet, rill, or gully erosion) and/or by the location of the erosional activity (surface or shoreline) or by the material being eroded (soil erosion).

Exchangeable sodium percentage (ESP): The percentage of the soil cation exchange capacity occupied by sodium ions. If this figure is 10 percent or higher, the soil is considered sodic.

Feasibility study: As applied to mining, the feasibility study follows discovery of the mineral and is done by the mining company. Its purpose is to analyze the rate of monetary return that

can be expected from the mine at a certain rate of production. Based on this study, the decision to develop the ore body may be made.

Flocculation: Aggregation of soil into lumps or masses.

Horizons, soil: Layers in the soil and overburden that differ in genetic characteristics, composition, or structure from adjacent layers. The various horizons in a soil are generally described by a diagram representing a vertical section of the soil called a profile. The horizons are designated as follows: A-horizon, topsoil; B-horizon, mineral soil; C-horizon, parent soil material, weathered or unweathered rock fragments, and minerals; D-horizon, a layer under the C-horizon which is unlike the parent material.

Hydraulic conductivity: A combined property of the conducting medium and the fluid that indicates the ability of the aquifer material to conduct water through it under a hydraulic gradient.

Inhibitory zones: Areas in the overburden that would prevent or limit plant growth if used as a plant-growing medium after mining.

Inoculation: Treating the soil by adding micro-organisms to it, or by adding soil or organic material containing desirable micro-organisms.

Interdisciplinary team (ID Team): As proposed by recent Forest Service regulations, the interdisciplinary team will be comprised of Forest Service personnel who collectively represent two or more areas of specialized technical knowledge about natural resources management applicable to the area being planned. The team will consider problems collectively, rather than separate concerns along disciplinary lines. This interaction will insure systematic, integrated consideration of physical, biological, economic, and other sciences.

Land-management plan: According to Forest Service regulations, each forest must have a forest plan, which outlines the most desired and alternative land uses for that site.

Leaching: To remove soluble constituents fr a substance by the action of a perco liquid.

Micro-organism: An animal or plant of m scopic size, especially a bacterium or proto

Mining plan: Submitted by the mining ope the mining plan outlines the steps the m company will take to mine and rehabilita site. The mining plan is submitted prior to up of mining operations.

Monitoring: In regard to disturbances cau mining, the site must be carefully observe lowing reclamation operations to insure reclamation goals are being met. Moni usually involves observations over time.

Mulch: Any non-living material placed on or near the soil surface for the purp protecting it from erosion or protecting from heat, cold, or drought.

Mycorrhizal: Describes a symbiotic asso of a fungus with the roots of certain plant

Organic matter: Matter composed of once organisms; matter comprised of carbon pounds.

Overburden: Materials overlying a mi deposit up to, but not including, the topso

Oxidation in soil: The combination o stances in the soil with oxygen. If the sub is a sulfide, this oxidation may result in an condition.

pH: Symbol for the negative common log of the hydrogen-ion concentration (acidit solution. The pH scale runs from 0-14, pH of about 7 considered neutral. A pH below 7 indicates acidity and a pH value 7 indicates alkalinity or a base.

Performance bond: A bond of liability pla a mining company. The bond specifies tions for determining the acceptability of mining and reclamation activities.

file: A diagram representing a vertical section the soils and overburden and showing the ıral horizons in that material.

ic soil: A sodic soil occurs when exchange- sodium ions are so concentrated in the soil they may adversely affect plant growth. An of 10 percent or higher, or an SAR of 10 or e may indicate a sodic soil.

ium adsorption ratio (SAR): A lab measure- t of the ratio of soluble sodium to soluble ium plus magnesium in soils. If the SAR is r more, the soil may be sodic.

: The loose, uncemented minerals and nic material on the immediate surface of earth that serves as a natural medium for the vth of land plants; in this definition, soil extends to the depth important for plant vth.

survey: A general term for the systematic nination of soils in the field and in labora- rs; their description and classification; the aping of kinds of soil; their adaptability for ous uses; their productivity.

ils: The overburden (soil and raw geologic erials) removed in gaining access to the sed mineral deposit.

Stockpiling: Storage of soils material for later use.

Storage areas: See Dumps.

Structure: Aggregates of primary particles of sand, silt, and clay into compound assemblies or clusters.

Texture: Relative proportion by weight of sand, silt, and clay.

Tillage: Any mechanical action that mixes or rips the soil.

Topsoil: The original or present dark-colored upper soil that ranges from a mere fraction of an inch to 2 or 3 ft thick on different kinds of soil. Most organic matter is concentrated in the top-soil. Usually refers to the "A" horizon of the soil profile.

Toxic soil: A soil containing concentrations of minerals so high as to be harmful to plants or animals.

Weathering: The process whereby larger particles of soils and overburden are reduced to finer particles by wind, water, temperature changes, and plant and bacteria action.

APPENDIX B

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Summarizes and discusses key questions and rules the soils scientist should consider when working in mining area reclamation. Topics include exploration and baseline data; soils and overburden analysis and sampling techniques; selecting storage areas; materials handling; spoils analysis; treating spoils problems; spoils surfacing; and monitoring and retreatment.

KEYWORDS: soils, revegetation, mining, mining area reclamation, mining area rehabilitation, land-management planning process.

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THE SEAM PROGRAM

The Surface Environment and Mining Program, known as SEAM, was established by the Forest Service to research, develop, and apply new technology to help maintain a quality environment while helping meet the Nation's mineral requirements. SEAM is a partnership of researchers, land managers, mining industries, universities, and political jurisdictions at all levels.

Although the SEAM Program was assigned to the Intermountain Station, some of its research projects were administered by the Rocky Mountain and Pacific Southwest Research Stations.

MINERAL USER GUIDES

Other User Guides for specialists involved in minerals activities are:

- User Guide to Vegetation, Gen. Tech. Rep., INT-64
- User Guide to Engineering, Gen. Tech. Rep., INT-70
- User Guide to Sociology and Economics, Gen. Tech. Rep., INT-73
- User Guide to Hydrology, Gen. Tech. Rep., INT-74
- User Guide for Wildlife (planned)
- User Guide for Visual Management (to be published as part of the National Forest Landscape Management Series)

To obtain copies of these guides, write: Intermountain Forest and Range Experiment Station, USDA Forest Service, 507 25th St., Ogden, UT 84401.

ORESТ SOIL BIOLOGY —
IMBER HARVESTING RELATIONSHIPS

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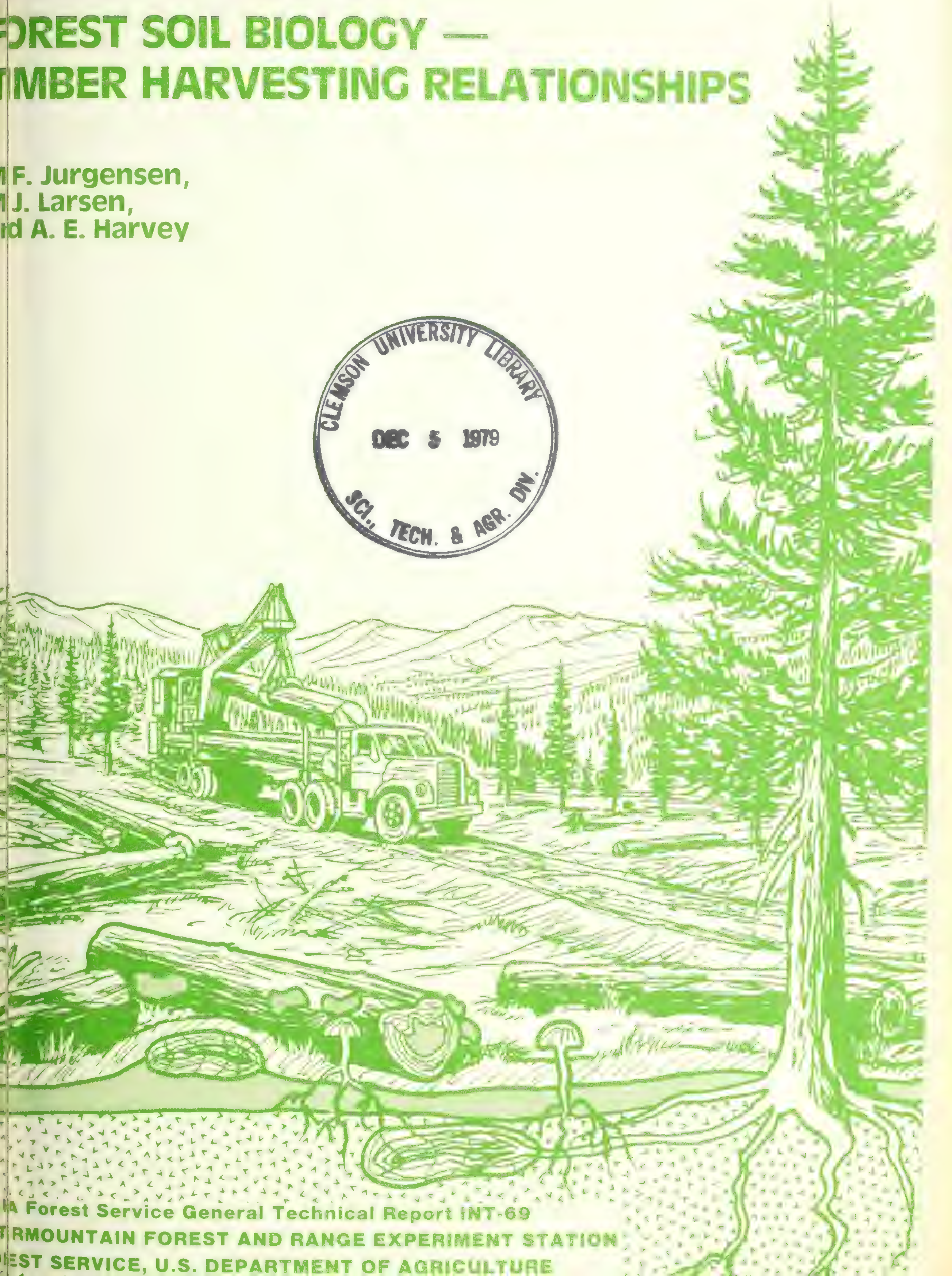

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FOREST SOIL BIOLOGY — TIMBER HARVESTING RELATIONSHIPS: A PERSPECTIVE

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RESEARCH SUMMARY

Timber harvesting has a pronounced effect on the soil microflora by removing essential woody food supplies and by changing soil chemical and physical properties. Greater activity of microorganisms following logging operations may affect site quality because of increased availability of soil nutrients and accelerated nutrient movement through the soil profile. Soil micro-organisms that function in the cycling of nitrogen generally are stimulated by timber removal, particularly if fire is used as part of postharvest site preparations. The effect of harvesting on the incidence of disease is a potential problem, but seems to be more related to the levels and types of logging residues on the site than to changes in soil properties. Decayed wood, as both a physical and chemical component of soil, appears to be an important factor in stand development and productivity on dry sites in the northern Rocky Mountains. The long-term implications of reducing the amounts of woody materials returned to the soil by increasing residue utilization is unknown. At present, no detrimental impact on site quality can be directly attributed to harvesting effects on soil micro-organisms; however, this may change as forest management goals emphasize more intensive use of existing stands.

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INTRODUCTION

The impact of timber harvesting on soil biological processes has received considerably less attention than the effects of timber harvesting on the physical and chemical properties of the soil. This neglect is due largely to the lack of obvious correlations between the activity of microorganisms and environmental change and to the difficulty in obtaining meaningful estimates of biological activity within the soil. Most investigations on the effects of timber harvesting on soil biology have been conducted in Europe, particularly in Russia (Bell and others 1974). Recently, because of controversies over clearcutting, interest in this subject has developed in North America.

This paper is intended to acquaint forest managers and research scientists with the functions of micro-organisms in forest soils and to explain how changes in these functions can result from timber harvesting operations. It is not meant to be a comprehensive state-of-the-art survey on this subject (see Harvey, 1976a), but rather a perspective of soil biology-harvesting relationships for the northern Rocky Mountain region based on selected literature and studies currently under way.

The manner by which harvesting operations affect soil microflora and their activities may be grouped into two categories: (1) direct effects caused by the removal of carbon and nutrient supplies (such as logs, pulp sticks, and chips) and (2) indirect effects related to changes in the chemical and physical properties of the soil (such as water content, temperature, oxygen-carbon dioxide levels, pH, available nutrients, and bulk density).

Biomass Removal

Removal of wood has an obvious influence on heterotrophic soil organisms. This loss of carbon, nitrogen, and associated minerals has a pronounced effect on the complex of micro-organisms dependent upon this material as a source of energy and nutrients. Thus, the removal of woody substrates would drastically alter the activity of fungi and other micro-organisms associated with wood decay. Similarly, the removal of tree foliage in total fiber harvest operations would affect the processes conducted by microorganisms in the soil litter.

Alteration of Soil Properties

The most widespread effects of timber harvesting on soil organisms are due to changes in the physical and chemical properties of the soil. Tree removal generally increases the levels of available water in the soil and raises soil temperatures (DeByle 1976). Since soil aeration is inversely related to moisture content, oxygen levels are reduced. Changes in soil pH also result from harvesting, especially if fire is used for slash disposal or site preparation. These changes in soil properties can greatly affect the numbers, diversity, and activity of the various soil organisms (Harvey and others 1976a).

IMPLICATIONS FOR FOREST MANAGEMENT

Of the many important functions of soil organisms likely to be influenced by timber harvesting, several are of special significance to forest management. These have to do with: the levels and availability of soil nutrients, the decay of woody plant material, and the activities of plant pathogens. Each of these is related to the level and type of timber operation and to possible site-preparation practices. Fire is an integral part of postharvest operations but, because of its large impacts on soil properties, will be discussed separately.

SOIL NUTRIENT LEVELS AND AVAILABILITY

Organic Matter Mineralization

Particular attention has been given to harvesting effects on the release of nutrients from nonwoody tree litter or from soil organic matter. This release, or "mineralization," of nutrients from organic materials by soil micro-organisms supplies a large portion of the nutrients required for tree growth. This is particularly true of nitrogen, phosphorus, and sulfur since nearly all of the nitrogen and approximately half of the phosphorus and sulfur are present in the soil as organic complexes (Mulder and others 1969). Inasmuch as the availability of most other soil nutrients is at least partially dependent upon the activity of soil microflora, changes in populations of soil micro-organisms may have important effects on nutrient availability and subsequent site productivity.

Studies, such as those by Cole and Gessel (1965) and Likens and others (1970), on nutrient release from litter have shown that the removal of forest vegetation increased decomposition of the forest floor. This increased availability of nutrients apparently is related to increased activity of soil microflora. Heterotrophic soil organisms increase after clearcutting as does the level of carbon dioxide in the soil (Piene 1974). This increase in carbon dioxide production by soil microflora would increase nutrient movement through the profile and contribute to leaching losses from the site (Cole and others 1975).

Increased activity by micro-organisms after logging is associated with increased soil temperature and (or) moisture levels in the cleared area. In certain instances, where timber harvesting has raised the ground water level to the soil surface or close to it, the reduction in soil oxygen levels can be severe enough to slow decomposition of organic matter (Bell and others 1974). In such operations as disking or bedding, where the litter is incorporated into the soil, decomposition of organic materials is greatly accelerated.

The significance of increased litter decomposition to the availability of soil nutrients and subsequent leaching losses depends on the site and on the type of harvesting operations. After clearcutting a Douglas-fir stand in Washington, Cole and Gessel (1965) found that the nutrients released after harvest remained in the root zone. Conversely, Pierce and others (1972), in their hardwood clearcutting study in New England, found nutrients significantly increased in the ground water and in neighboring streams. Investigators in the northern Rocky Mountain region have also reported increased losses of nutrients after harvesting (Hart and DeByle 1975); however, periods of accelerated nutrient losses are generally of short duration and continue only until the understory and herbaceous plants reestablish on the site, usually within a few years (Packer and Williams 1976).

Nitrogen Availability

Almost all nitrogen in the soil is present as organic forms and usually is the nutrient most limiting plant growth. Consequently, the effects of timber harvesting on the soil microflora would likely have their greatest impact on nitrogen cycling. These effects on soil nitrogen can be broadly classified as follows: the biological conversion, or "fixation," of atmospheric nitrogen into organic complexes, the nitrification of ammonium to nitrate, the losses of nitrate from the soil by denitrification. The mineralization of ammonium from organic nitrogen complexes was discussed earlier.

Dinitrogen Fixation

In natural ecosystems, the atmosphere supplies nitrogen to the soil through the fixation of inert nitrogen gas into forms useful to plants. With the recent increases in fertilizer costs, greater interest has centered on increasing the amounts of nitrogen added to the soil by biological fixation. Most of this research has been agricultural, such as the much-publicized attempts to develop nitrogen-fixing strains of corn and wheat. Nitrogen fixation in certain forest ecosystems is of considerable importance, particularly for replacing nitrogen losses caused by harvesting or fire.

SYMBIOTIC ORGANISMS

Symbiotic nitrogen fixation is the result of an association between a higher plant and a micro-organism capable of fixing atmospheric nitrogen. The best known relationship of this type is between leguminous plants and the bacterial genus *Rhizobium*. Commercially important legumes, such as soybeans, peas, and alfalfa, have been found to add as much as 175 pounds of nitrogen/acre/year (200 kilograms/hectare/year) to the soil. Most work has centered on agricultural systems and, with the exception of black locust, little is known about the extent or significance of the *Rhizobium*-legume association in forest ecosystems (Wollum and Davey 1975).

Other nitrogen-fixing relationships between symbiotic organisms are found in a wide variety of nonleguminous plants. Over 100 plant species, including alder (*Alnus*) and snowbush (*Ceanothus*), form nitrogen-fixing root nodules (Youngberg and Wollum 1970). Appreciable amounts of nitrogen can be fixed by these nonleguminous plants. Field studies on snowbush and red alder have shown nitrogen additions of over 90 and 275 pounds/acre/year (100 and 300 kilograms/hectare/year), respectively (Wollum and Davey 1975).

Timber harvesting increases the contribution of nitrogen-fixing plants to soil nitrogen levels in the postharvest period. Clearcutting in the Douglas-fir region of western Washington and Oregon favors development of alder and snowbush in the subsequent stand. Opening of the forest canopy drastically alters the composition of the understory and most likely increases the representation of shrub and herbaceous nitrogen-fixing plants (Schultz 1976). The use of clovers as a cover crop after harvesting is also being considered in Southern pine stands (Jorgensen 1978). Additional information is needed on the distribution and function of nitrogen-fixing plants in forest stands and how their occurrence is affected by management practices.

NONSYMBIOTIC ORGANISMS

In contrast to the symbiotic nitrogen-fixing plants, the significance of free-living, nitrogen-fixing micro-organisms in soil is unclear. This group of organisms, with the exception of the autotrophic blue-green algae, are dependent on organic matter in the soil as an energy and carbon source. Generally, little nitrogen fixation by nonsymbiotic organisms occurs in agricultural soils (Jensen 1965); however, appreciable nitrogen gains have been reported in certain prairie, forest, and peat soils, where organic matter is not routinely removed form the site (Moore 1966).

Most soil and stand changes resulting from timber harvesting would favor non-symbiotic nitrogen-fixing organisms. The increases in soil temperature, pH, and moisture level after logging would all tend to raise nitrogen-fixation rates. Greater light penetration to the soil surface would also promote the activity of the nitrogen-fixing blue-green algae. Conversely, observed increases in soil ammonium and nitrate concentrations following harvesting could inhibit the nonsymbiotic nitrogen-fixing microflora.

Preliminary results from a study we are conducting in Montana indicate at least a slight increase in nitrogen-fixation after clearcutting; however, the amounts of nitrogen added to the soil are still quite low. How long after the harvest such increases in nitrogen fixation rates will continue is presently unknown.

Nitrification

The effects of forest practices on nitrification are receiving considerable attention because of nitrate pollution problems in ground water, streams, and lakes. In contrast to the positively charged ammonium ion, the nitrate anion readily moves through the soil profile. The organisms generally assumed to be most active in the nitrification process are a select group of autotrophic bacteria. These nitrifying bacteria are not directly affected by soil organic matter because they obtain their energy solely from the oxidation of nitrogen compounds and use carbon dioxide as a carbon source; however, organic matter indirectly affects nitrification by influencing soil moisture levels, soil temperature, and cation exchange capacity.

Timber harvesting, particularly clearcutting, will drastically increase populations of nitrifying bacteria in certain soils. Clearcutting increased bacterial populations in New Hampshire and resulted in much higher levels of nitrate in neighboring water-sheds (Likens and others 1970); however, the loss of nitrate after clearcutting has been found to be much lower in other parts of the country (Reinhart 1973). These variable effects of harvesting seem to be related to stand differences in organic matter accumulation, to soil temperature and moisture pattern, and to soil texture (Stone 1973).

Denitrification

The effect of timber harvesting on losses of soil nitrogen through the biological conversion of nitrate to gaseous nitrogen forms is unknown. In fact, the extent of this nitrogen transformation occurring under forest conditions has hardly been investigated (Wollum and Davey 1975).

Logging operations have the potential of increasing denitrification rates. Since denitrification is carried out by anaerobic bacteria, the increases in soil water content after harvesting and the resultant lowering of oxygen levels would favor such organisms. An increase in soil temperature or pH could also stimulate the denitrifying microflora (Broadbent and Clark 1965).

An adequate supply of nitrate is of particular importance to the denitrifying bacteria. As noted earlier, nitrification rates in certain soils may be enhanced after removing the overstory. Such higher levels of soil nitrate may lead to greater denitrification and resultant nitrogen loss, but, at present, this is speculation.

INTERACTIONS WITHIN THE RHIZOSPHERE

In addition to symbiotic nitrogen-fixing relationships, other more subtle root-micro-organism interactions may also be affected by timber removal. The rhizosphere, or that portion of the soil immediately adjacent to and directly under the influence of the plant root, is a site of enhanced microbial activity. The metabolic products from the roots and associated microflora are important in mineral weathering. Boyle and Voigt (1973) attributed increased potassium availability and, subsequently, increased plant uptake to nutrient release within the rhizosphere (figure 1). Also, nitrogen fixation and denitrifcation rates are higher in the rhizosphere (Trolldenier 1977).

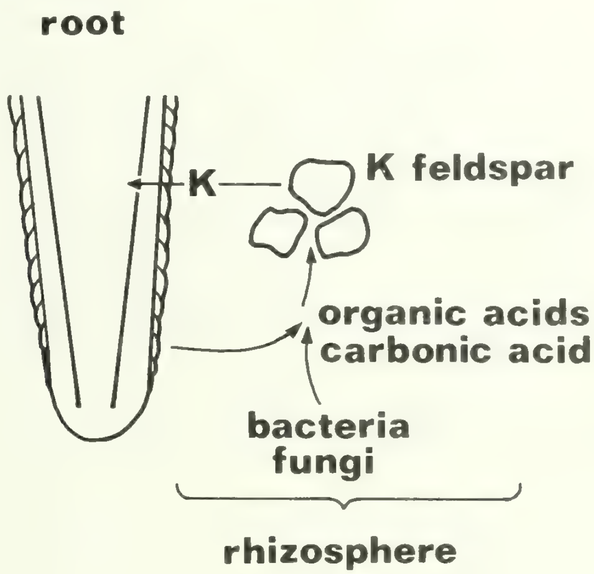

Figure 1.--Impact of rhizosphere microflora and plant roots on nutrient availability.

Differences occur within the rhizosphere among various plant species and site properties affect the populations of microorganisms. Changes in both the overstory and understory composition could alter the rhizosphere and affect nutrient availability. As yet, this effect of timber harvesting has not been explored.

WOODY RESIDUE DECAY

Timber harvesting effects on the incidence of woody residue, in contrast to leaves, twigs, or bark, are being considered separately. This is due to the distinctive chemical composition of wood, the unique microflora active in its breakdown, and the possible role it may have in maintaining site quality. Depending on the type and past history of a site, woody materials in varying amounts and in different stages of decay may be found at the soil surface or partially imbedded in it.

Large woody residues can persist on a site for several hundreds of years. McFee and Stone (1966) found in northern New York that up to 30 percent of the surface foot of soil volume was made up of decayed wood. Harvey and others (1976b) demonstrated similar volumes of woody residues in a western Montana soil. These persistent woody materials are formed mostly from conifer residue by brown rot fungi. Wood decomposed by white rot fungi does not persist and appears to be more characteristic of hardwood stands.

The Function of Residue Decay

The most important effect of decayed wood on site quality seems to be in its moisture-holding properties. Decayed wood has a larger water-holding capacity and dries out more slowly than other soil components (table 1). A more favorable moisture regimen in decayed wood makes this substrate important for seedling establishment and subsequent stand growth. Seedlings of certain trees, such as birch and hemlock, are commonly observed growing on decaying logs.

Table 1.--*Nitrogen fixation rate (grams x 10^{-9} N/day/gram of dry soil) and moisture content (percent dry weight) from various forest sites in Montana, July 24,* [illegible][1]

Stand and habitat type designation[2]	Humus		Decayed wood		First 5 cm of mineral soil	
Pseudotsuga menziesii (PSME/PHMA)	5.9	53	22.8	172	2.3	11
Larix occidentalis/P. menziesii (ABLA/CLUN)	15.8	146	32.3	301	3.2	36
Tsuga heterophylla (TSHE/CLUN)	39.5	201	30.6	226	2.1	23

[1]Determined by acetylene reduction technique (Hardy and others 1968).
[2]*Pseudotsuga menziesii/Physocarpus malvaceus*; *Abies lasiocarpa/Clintonia uniflora*; and *Tsuga heterophylla/Clintonia uniflora* are habitat type designations in western Montana (Pfister and others 1977).

Even for an older stand, the decayed wood fraction of the soil may play an important role, particularly on dry sites. Our recent studies in Montana have shown that decayed wood is a major site of mycorrhiza particularly during the dry portion of the growing season (table 2). Higher soil temperatures and reduced moisture levels in the surrounding mineral and litter layers restrict root colonization and growth of mycorrhizal fungi (Harvey and others 1976a). Decayed wood is generally more acid than other soil components, which favors development of mycorrhizal roots (Bowen and Theodorou 1973).

Table 2.--*Active ectomycorrhizal root tips/liter of soil from various forest sites, summer 1976*[1]

Stand and habitat type designations[2]	Humus	Decayed wood	First 5 cm of mineral soil
Pseudotsuga menziesii (PSME/PHMA)	12.8	17.2	10.2
Larix occidentalis/P. menziesii (ABLA/CLUN)	109.8	26.2	16.7
Tsuga heterophylla (TSHE/CLUN)	203.7	108.4	41.8

[1]From Harvey and others 1978

[2]*Pseudotsuga menziesii/Physocarpus malvaceus*; *Abies lasiocarpa/Clintonia uniflora*; and *Tsuga heterophylla/Clinton uniflora* are habitat type designations in western Montana (Pfister and others 1977).

Our studies have also shown that decayed wood is a site of nitrogen fixation, both in and on the soil (table 1). Of particular significance is the fact that on a dry area, decayed wood was a more active site for nitrogen fixation than either the litter or the mineral soil. In the Southeast, both decaying chestnut logs and the leaf litter layer had comparable fixation rates (Cornaby and Waide 1973).

The impact of timber harvesting on the amounts of decayed wood on a site is obvious--the more timber removed, the less residue remains to be incorporated into the soil. More intensive residue utilization, coupled with fire as a slash disposal method, could drastically alter this woody soil component; consequently, some woody material should be left on certain sites after harvest to guard against long-term reduction in site productivity. This may be especially true for those soils characterized by prolonged droughty conditions or by having low levels of soil nitrogen.

ACTIVITIES OF PLANT PATHOGENS

The very nature of forest harvesting imposes radical changes on the ecosystem. These changes, in turn, directly or indirectly affect forest pathogens. Whether related to natural forces or to man's activities, tree residues left in place can become disease problems. Stumps of fallen trees, other woody residue, and roots in the soil are essential for the fruiting and survival of cull-causing and root-rotting fungi (Boyce 1961). Diseases, such as *Lophodermium* or *Neopeckia*, that attack foliage and produce spores or dead and fallen needles, can also represent a hazard (Hepting 1971). Thus, adequate reduction of logging residues can suppress many types of diseases. Conversely, accumulated residues may intensify these problems.

Disease incidence can also be affected by the increased amounts of available nutrients after logging. Fertilizer applications have aggravated some disease problems both in nurseries and in the field (Hesterberg and Jurgensen 1972). These nutrient additions influence the incidence of disease by changing the physiological condition of the fertilized tree. Certain nutrients, particularly nitrogen, can also affect the survival and growth of the saprophytic stage of many root pathogens (Huber and Watson 1974). It seems unlikely that the increased amount of nutrients available after harvesting would be sufficient to cause disease responses similar to those caused by fertilizer application, but this question needs to be further investigated.

FIRE

Considerable research has been done on the effects of both wildfire and prescribed fire on soil biology. Fire drastically reduces microorganisms, particularly bacteria in the surface soil horizons (table 3). The soil microflora usually recovers quite rapidly, frequently to a population level far greater than the original. In severe habitats, such as chaparral stands in California, recovery may be delayed (Dunn and DeBano 1977).

Table 3.--*Changes in populations of soil micro-organisms following burning*[1]

Site	Horizon	Sampling (after burn)	Treatment	Bacteria[2]	Fungi[2]
	inches	days			
Pseudotsuga menziesii (Oreg.)	0-1.5	210	Unburned	2,910	6
			Burned	119,500	58
P. menziesii (Oreg.)	0-2.0	2	Unburned	26,000	240
			Burned	60,000	136
	0-2.0	180	Unburned	33,000	570
			Burned	36,000	138
Pinus banksiana (Minn.)	0-1.0	35	Unburned	800	30
			Burned	710,000	100

[1]Ahlgren and Ahlgren 1965; Neal and others 1965; Wright and Tarrant 1957.
[2]Bacterial and fungal populations expressed in thousands/gm of dry soil.

Increased microbiological activity in burned soils can be related to a more alkaline soil pH, to increased carbon availability, and to higher ammonium levels found after fire. Soil nitrification rates are likely to increase since ammonium is normally the limiting factor for the nitrifying population. The rise of soil pH after a fire would also favor these organisms (table 4).

Organisms active in the nitrogen cycle have been of special concern since substantial losses of organic nitrogen can occur through volatilization during a fire (Knight 1966); however, gains of over 18 pounds of nitrogen/acre/year (20 kilograms/hectare/year) were found on some sites in the Southeast that were burned annually over a 20-year period (Jorgensen and Wells 1971). Nitrogen gains after fires have been attributed to a larger legume component in the ground vegetation or to greater activity of nonsymbiotic nitrogen-fixing organisms (Stone 1971).

Table 4.--*Changes in available nitrogen and pH by burning*[1]

Site	Horizon	Sampling (after burn)	Treatment	pH	Ammonium	Nitrate
		days			- - - - [illegible] - - - -	
Pseudotsuga menziesii (Oreg.)	0-2 in.	2	[2]Unburned	5.9	5	1
			Burned	5.9	38	4
Chaparral (Calif.)	0-1/2 in.	1	[3]Before	--	1	1
			After	--	7	1
Tsuga canadensis (Mich.)	Litter (O_1)	5	Unburned	4.8	75	27
			Burned	6.9	180	100
Larix occidentalis (Mont.)	Litter (O_2)	1	Before	6.0	15	17
			After	7.0	230	16

[1]Mroz and others 1979; Dunn and DeBano 1976; Neal and others 1965.
[2]Samples taken from a burned area and from an adjacent control.
[3]Samples taken from a particular site before and after a fire.

Prescribed fire can also have an effect on disease problems in subsequent stand development. Fire can sterilize and change the physical-chemical characteristics of the upper soil horizon. Frequently, feeder-root pathogens, such as *Fusarium* and *Phytopthora*, are well adapted to these new soil conditions (Wright and Bollen 1961). The root pathogen *Rhizina undulata*, whose spores are activated by exposure to heat, is often active on young conifer seedlings after burning (Morgan and Driver 1972). Thus far, disease problems related to fire incidence have not been significant.

SUMMARY AND CONCLUSIONS

Interactions between logging systems, silvicultural treatments, and their respective residues will bring about changes in the soil microflora. Many studies have shown enhanced decomposition of soil organic matter by micro-organisms with resultant increases in nutrient availability and in the leaching of nutrients through the soil. For most sites, these losses generally are small and last only a few years.

A different situation prevails after logging cool, wet sites where a large buildup of surface organic litter has occurred. Here increased microbial activity, coupled with adequate rainfall for leaching, causes appreciable nutrient losses. Of particular significance are possible increases in the nitrifying populations that can bring about high losses of nitrate nitrogen.

Interest is developing in the effects of tree harvesting on microorganisms that function in the cycling of nitrogen. Postharvest operations that include fire as part of site preparation have more effect on these organisms than do nonburning operations. As yet, an insufficient data base prevents definite conclusions as to whether these effects are generally detrimental or beneficial.

Harvesting effects on disease problems appear to be related to the amount and type of residue on the site. As more of this material is removed because of more intensive utilization standards, the incidence of disease should decrease. Fertilizers are known to favor certain disease organisms. Whether the increase in the availability of soil nutrients after fire or timber harvesting would cause a similar effect is unclear.

Most studies describing the impact of timber harvesting on the environment stress the loss of various nutrients in wood and their relation to the total nutrient budget; however, from the standpoint of soil biology, the loss of wood as a soil component may be of equal or of more importance to site quality. The trend toward greater use of logging residues and cull timber will dramatically reduce the amounts of woody matter returned to the soil. The long-term implications of reducing this woody-organic base in soil is generally unknown. Our studies suggest that these materials should remain on dry sites in the northern Rocky Mountains if they do not constitute a wildfire hazard.

Most of the information on the biological consequences of timber harvesting is derived from a few studies investigating treatments designed to give the highest possible impact to the site. The infinite variations in harvesting techniques, stand age and condition, postharvest treatment, soil and climatic differences that characterize forest conditions make it difficult to draw general conclusions; however, at this time, no widespread detrimental impact on site quality can be directly attributed to harvesting effects on the soil microflora. These environmental effects may change as harvesting systems emphasize more intensive use of the stand.

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Timber harvesting has a pronounced effect on the soil microflora by wood removal and changing properties. This paper gives a perspective on soil biology-harvesting relationships with emphasis on the northern Rocky Mountain region. Of special significance to forest management operations are the effects of soil micro-organisms on: the availability of soil nutrients, particularly nitrogen; the decay of woody plant material; and tree disease incidence. At present, no widespread detrimental impact on site quality in the northern Rocky Mountain region can be directly attributed to harvesting effects on the soil microflora.

KEYWORDS: timber harvesting, soil micro-organisms, nutrient cycling, nitrogen fixation, nitrification, denitrification, mycorrhizae, disease, fire, residues, decay, mineralization, rhizosphere.

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

- Billings, Montana
- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with University of Montana)
- Moscow, Idaho (in cooperation with the University of Idaho)
- Provo, Utah (in cooperation with Brigham Young University)
- Reno, Nevada (in cooperation with the University of Nevada)

URFACE ENVIRONMENT & MINING
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DA FOREST SERVICE PROGRAM

USER GUIDE to ENGINEERING

Mining and Reclamation in the West

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GENERAL TECHNICAL REPORT INT–70
INTERMOUNTAIN FOREST AND RANGE
EXPERIMENT STATION
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

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RESEARCH SUMMARY

The engineer working on mined land must be aware of potential impacts of mining, as well as the techniques available that can help mitigate these impacts. This guide covers major points of concern to the engineer involved in planning for minerals activities including: preliminary site reconnaissance; computer-aided planning tools; transportation systems; minerals exploration and development facilities; geotechnical engineering and mining practices; mass stability; air quality; and reclamation equipment.

Information is presented in a question/rule/discussion format, and includes supporting graphic material, notes on additional sources of information, a glossary, and an index.

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INTRODUCTION

MINERAL AND NONMINERAL RESOURCES

An adequate, reliable supply of minerals is essential to the economy and security of the United States, because minerals provide the physical basis for almost all activities of U. S. citizens. While imports can satisfy an important part of the country's minerals demand, they make the U. S. vulnerable to the economic and political decisions of foreign countries. Thus, the mineral desposits within the U. S. are a most important source of this nation's supply.

A substantial portion of the domestic minerals supply presently comes from lands managed by the Federal Government. Federal lands contain a majority of the remaining metallic minerals, as well as major resources of coal, oil shale, geothermal steam, uranium, and oil and gas. These same Federal lands, however, also contain valuable nonmineral resources, including timber, forage, water, wildlife, scenic landforms, and wilderness. The Government's holdings of such resources are now among the most significant in the world.

While it is clearly in the national interest to provide for the identification and production of the mineral resources on Federal land, it is also necessary to provide for a sustained high-level output of the various renewable resources on that land. Thus, the demand for mineral development must be balanced against the demand for renewable resources and the land-management agency's responsibility to reasonably protect the environment affected by mineral-related operations.

MINERALS IN THE LAND-MANAGEMENT PLANNING PROCESS

The Forest Service, as one of the agencies responsible for Federal land management, has a relatively sophisticated planning program for the management of nonmineral resources on land under its jurisdiction. Historically, however, Forest Service land-management and planning systems have treated minerals as a distinct category outside of the mainstream of the land-management planning process. There are two basic reasons for this separation:

1. The mining and mineral leasing laws have tended to make mineral activity the preferred use on any Federal land open to such activity. The thinking has been that on lands open to mineral activity, mineral development will generally override the designated primary nonmineral uses.

2. Planning for use of the mineral and nonmineral resources is complicated considerably by the difficulties of identifying and estimating the value of mineral resources. Mineral resources can be found only through costly and risky exploration. Therefore, land-management planning has tended to concentrate, at least until a mineral discovery is made, on the surface resource potential of the land.

The long-standing premise that mineral activity is always the most valuable use of a tract of land is increasingly being challenged. Many mineral deposits being discovered today are of lower grade and located at greater depths, and are therefore more expensive to find and mine than the high-grade surface deposits formerly developed. Another significant factor is that nonmineral surface resources are now also considered to be scarce, and their value has increased accordingly.

Hence, when all the mineral and nonmineral values are weighed for a particular proposal at a specific location, the value of the mineral resources may be outweighed by the value of the nonmineral resources. The process of weighing values usually occurs in an Environmental Assessment required by the National Environmental Policy Act of 1969 (NEPA) and is basic to determining the proper mix of uses for any given land area.

Given this situation of mineral and nonmineral values on the same tract of Federal land, decisions as to the proper use of a particular tract of land will always involve balancing the values of mineral and nonmineral resources. If this balancing is to be done in a reasonable manner, adequate information and analysis of all values are needed.

BACKGROUND: THE FORMATION AND MISSION OF SEAM

Realizing the complexity of land-use decisions, the Forest Service chartered the Surface Environment and Mining program (SEAM) in 1973 to coordinate research, development, and application related to land impacts resulting from minerals exploration and development in the West. From 1973 to 1979, SEAM sponsored more than 150 research and development projects. Together, the projects have greatly added to the body of knowledge surrounding the management of land in mineralized areas. (For purposes of this discussion, mineralized areas are defined as those areas that have some potential for mining.)

To get this knowledge to the specialists in the field in a form they could readily use, SEAM brought together researchers from industry, Federal agencies, and the academic community to share their practical knowledge and study results in a series of workshops. The information presented at these workshops is organized into five user guides. Each guide focuses on a specific discipline involved in managing surface resources that may be affected by mineral activities and is written for specialists in these disciplines. The guides will also be of use to land managers, land planners, and other specialists, because many activities related to minerals-area management demand that a variety of skills be applied to achieve an integrated approach.

In addition to the User Guide to Engineering, guides have been written for vegetation, hydrology, soils, and sociology and economics. Cross-referencing among these guides is provided in the index. A handbook for minerals specialists has also been written. A handbook for land managers will provide a general overview of administrative considerations surrounding mineral commodities commonly explored for and developed on national forest lands administered by the Forest Service. Concurrent with the development of the SEAM user guides, a USDA handbook on visual management related to mining and reclamation, entitled "Mining," is in press as volume 2 of the National Forest Landscape Management Series. A guide for the wildlife specialty is also planned. All guides will be updated periodically to keep them current with research findings.

The purpose of the guides is to help specialists more clearly understand their role in mineral exploration and development activities by outlining some of the major considerations they must address to insure that such activities integrate with land-management plans; that impacts are mitigated to a reasonable degree; and that reclamation meets state-of-the-art performance standards. Perhaps by using these guides as a common starting point, those involved in minerals management can more easily work together toward achieving these common goals: (1) appropriate considerations of mineral values in land-management planning; (2) protection of surface resources during mining activities; (3) reclamation of surface-mined land to a productive use; and (4) mitigation of the adverse effects resulting from minerals development.

HOW TO USE THIS GUIDE

The chapters of this guide cover topics that concern the engineer during both land-management planning and any subsequent minerals activity. Within each chapter, major topics will be addressed in this way:

- Considerations: These are the questions the engineer should ask about each topic.
- Rules: These general statements answer the questions and direct the engineer toward the type of site-specific information the land manager may need to make decisions. Rules are set in italic type.
- Discussions: The discussions explain the reasoning behind the rules and in some cases give specific examples of how the rules are applied.
- Additional Information: Here the reader will find basic references to further information on the topic discussed.

The aim of this format is to help define the role of the engineer in minerals management.

The guide is not intended to be a "cookbook" on rehabilitation techniques. Rather, it is intended to set up a logical thought process based on a question/answer approach. Such an approach allows for flexibility, eliminates unnecessary data gathering, helps simplify technical decisionmaking, and allows for a systematic documentation of the decisionmaking process. We hope that this organization of material will make the guides equally useful to users in industry, Federal and State agencies, and the academic community.

The role of the Forest Service staff is illustrated in table 1, "Stages of Mineral Exploration and Development Activities," and table 2, "Roles of Forest Service Specialists in Minerals Activities," which follow this introduction. As you will note, the Forest Service engineer will advise, review, and monitor. For example, although design and construction take place during several stages of minerals activities, the engineer reviews these plans when the operating plan is submitted prior to development and, if necessary, suggests revisions to the plan. Then, during operations and reclamation stages, the Forest Service specialist will monitor these activities according to the approved operating plan. In this way, the effects of the development will be managed in a proactive, rather than reactive mode. In other words, rather than reacting to crises, the engineer will be part of the forest's interdisciplinary (ID) team from the time land-management planning begins. Then, if and when mineral activities occur, the team will have foreseen potential problems and will have determined general rehabilitation objectives in advance.

Both land-management planning, in its broader application, and site-specific operational planning for mineral activities on National Forest System lands require the full range of interdisciplinary efforts so that information on both the mineral and nonmineral values can be presented to the decisionmaker in an integrated manner. The interdisciplinary approach to planning is uniquely suited to giving the best available assessment of the spectrum of opportunities and problems of managing surface resources that may be affected by mineral-related operations and the requirements needed for reasonable protection of nonmineral resources. Soils, vegetation, hydrology, topography, geology, wildlife, climate, and social and economic information are some of the factors that must be considered by the ID team.

Land management and planning must always proceed on the basis of existing information. In the case of mineral resources, this will almost always be difficult because the mineral resources are hidden beneath the surface and information is provided in increments as exploration proceeds. One of the principal goals of Federal land management, therefore, should be to improve such management by obtaining better information about subsurface values and integrating this information into the decisionmaking process.

When using this guide, the reader should keep in mind that, for the most part, the information is concerned with scientific considerations. While other factors, particularly cost and legal constraints, are a crucial part of the planning process, discussion of these aspects is limited here.

One final note: Engineering skills are as much an art as a science. To clarify specific points or to keep up with new developments, readers are urged to contact the workshop participants who contributed to this guide.

Additional Information:

For more information on the mining process, refer to "Anatomy of a Mine," USDA For. Serv. Gen. Tech. Rep. INT-35. 1977. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Table 1. — *Stages of mineral exploration and development activities*[1]

Prospecting	Exploration	Feasibility studies/operating plan
A. Administrative Action No administrative action required; however, some evidence of mineralization or a hunch	**A. Administrative Action** Permit/Lease Notice of intent from miner (for certain commodities, may also serve as operating plan if there is minimal surface disturbance) Exploration license EA may be necessary See Handbook for Land Managers (in press) for variation within commodities	**A. Administrative Action** Submission of necessary permits (EA, EIS, etc.) and operating plan—see Handbook for Land Managers (in press) for variation within commodities
B. Activities Literature search Geological inference Evaluation of existing data Research on rights to land/minerals	**B. Activities** More intensive literature search Access road construction On-site testing and evaluation of data—geological, geochemical, geophysical, drilling, sampling, shaft sinking Seismic activity Acquiring land/mineral rights Rehabilitation of exploration impacts Environmental and socioeconomic studies	**B. Activities** Feasibility studies Grade and size of deposit Cost of mining and rehabilitation Market Fiscal Technical studies—mine design Environmental and socioeconomic studies (if not done during exploration) Decision to proceed with development Preparation of operating plan including rehabilitation program and end use Ordering of equipment
C. Environmental Impacts Minimal, if any	**C. Environmental Impacts** Roads Drill holes Drill pads Dozer holes Exploration camps	**C. Environmental Impacts** Generally none at this stage
D. Tasks for the Engineer None at this point	**D. Tasks for the Engineer** Review of plans to reclaim land impacted by exploration Review and assist in engineering aspects of environmental studies	**D. Tasks for the Engineer** Review adequacy of operating plan for: Engineering considerations— air pollution transportation facilities surface-mine facilities mine-waste disposal embankments tailings dams and impoundments subsidence Engineering aspects of end use

[1] The various phases have considerable overlap. The material provided for each phase is illustrative, not complete, and considerabl variation is found by commodity. The existence of a forest plan is assumed. Tasks (D) are primarily input from a land-managemen agency's engineer. For purposes of discussion, the terms reclamation and rehabilitation are used interchangeably, and mining includes oi and gas activities.

Development[2]	Mining/reclamation	Postmining
A. Administrative Action Approval of necessary operating plan	A. Administrative Action No administrative action required. Mining overlaps with development and reclamation overlaps with mining; reclamation of previously mined areas occurs concurrently with new mining as stipulated in operating plan Any changes in operating plan	A. Administrative Action Release of reclamation bond
B. Activities Securing of financing More extensive testing and definition of the mineral Construction of transportation routes and utilities Construction of mine and processing plant (facilities, water supply, etc.) Construction of waste deposits Continued evaluation of data Change mining plan if necessary	B. Activities Extraction of mineral Processing of mineral Depositing wastes Operation of transportation systems Rehabilitation Monitoring for any changes in biological and physical environment Amend mining and rehabilitation plan if necessary	B. Activities Surface owner manages land after bond release Monitoring for any changes in biological and physical environment Management and maintenance for end-use objective
C. Environmental Impacts Mine Processing plant Waste dumps Transportation and access routes Utilities Increased population resulting from construction	C. Environmental Impacts Impacts directly related to operational aspects of mining; impacts are strongly affected by commodity mined and type of operation	C. Environmental Impacts Directly related to management and maintenance activities
D. Tasks for the Engineer Monitor engineering-related activities for conformance to operating plan Advise on plan revisions when necessary	D. Tasks for the Engineer Advise from an engineering standpoint on release of reclamation bond	D. Tasks for the Engineer Monitor any continued impacts from engineered structures Manage structures for end-use objective

[2] Development is herein defined as the phase which begins after the right to mine has been established.

Table 2.—*Roles of Forest Service specialists in minerals activities*

	Prospecting	Exploration	Feasibility studies/operating plan
Vegetation specialist	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in vegetation aspects of environmental studies	Review adequacy of operating plan for: Reclamation program — species selection plant materials site preparation planting methods cultural treatments Monitoring/retreatment program for vegetation Vegetation aspects of end use
Soils scientist	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in soils aspects of environmental studies Review soils inventory progress in the the mineralized areas; if needed, recommend timely completion or upgrading	Review adequacy of operating plan for: Reclamation Program— soils surveys storage area selection materials handling plans spoils analysis plan spoils treatments spoils surfacing and erosion control Monitoring/retreatment program for soils Soils aspects of end use
Hydrologist	Establish baseline water-quality monitoring as needed according to plan	Review of plans to reclaim land impacted by exploration Review and assist in hydrologic aspects of environmental studies	Review adequacy of operating plan for: Hydrologic considerations— surface water subsurface water snow management roads impoundments mine drainage Hydrologic aspects of end use
Engineer	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in engineering aspects of environmental studies	Review adequacy of operating plan for: Engineering considerations— air pollution transportation facilities surface-mine facilities mine-waste disposal embankments tailings dams and impoundments subsidence Engineering aspects of end use
Economist	Monitor factors which affect supply and demand for minerals Make forecasts of supply and demand Predict probability	Analyze costs and benefits of alternative exploration methods Participate with the sociologist in identification of existing and emerging issues	Provide expertise in environmental analysis process: issue identification decision criteria cost/benefit analysis of alternatives tradeoff and opportunity-cost evaluations Analyze effects of development on: demand for surface resources human behavioral patterns community economics
Sociologist	Identify the basic social/cultural descriptors of the affected communities Note current trends	Assist in structuring public involvement plan for appropriate: issue identification issue analysis mitigation action Identify critical trigger points from a social perspective	Provide expertise in environmental analysis process: decision criteria issue identification Analyze effects of development on the cultural and political community Consider effects of alternative plans on social well-being

Development	Mining/reclamation	Postmining
Monitor vegetation impacts and activities for conformance to operating plan. Advise on plan revisions when necessary	Monitor vegetation impacts and activities for conformance to operating plan. Advise on plan revisions when necessary Advise from a vegetation standpoint on release of reclamation bond	Monitor any continued impacts on vegetation Manage vegetation for end-use objective
Monitor impacts on soils Monitor soils-related activites for conformance to operating plan. Advise on plan revisions when necessary	Monitor soils impacts and activities for conformance to operating plan. Advise on plan revisions when necessary Advise from a soils standpoint on release of reclamation bond	Monitor any continued impacts on soils Manage soils for end-use objective
Monitor impacts on hydrology	Monitor impacts on hydrology and hydrologic aspects of rehabilitation program Have hydrologic input into release of reclamation bond	Monitor any continued impacts on hydrology Manage hydrology for end-use objective
Monitor engineering-related activities for conformance to operating plan Advise on plan revisions when necessary	Advise from an engineering standpoint on release of reclamation bond	Monitor any continued impacts from engineered structures Manage structures for end-use objective
Record costs Monitor economic changes	Record costs Monitor economic changes	Monitor to determine accuracy of predictions for future use
Monitor Record changes Identify areas of individual or group stress relating to mineral activity and make recommendations to mitigate effects	Monitor Record changes	Monitor and record critical changes to establish new baseline situation

Chapter 1
PRELIMINARY SITE RECONNAISSANCE

Chapter Organizer: William Boley

Major Contributor: William Boley

During the development of the forest plan, broad decisions affecting all the resources on national forest lands will be made, as well as decisions about what activities should take place on a given piece of land. Before such allocation decisions are made, site-specific information may be needed. Depending on the type of mining and the laws that control a specific mineral, the location of a mining or processing operation may be influenced, and in some cases dictated, by the land-management agency. In many cases, a minerals operation is influenced by road access, and the complete process may be changed because of site and access conditions. During preliminary site reconnaissance, the Forest Service engineer, as a member of, or contributor to, the ID team, will be involved in collecting such site-specific information.

What is the purpose of preliminary site reconnaissance in relation to mining?

Preliminary site reconnaissance will help to assess the quality and quantity of the effects of minerals activities on national forest lands. This information will be useful in offsetting the short amount of time the Forest Service has to respond to a mineral company's request for a minerals lease or an exploration permit.

Discussion:

Although site reconnaissance can be conducted at any time, from the first stages of planning on Forest Service land until a minerals operation is approved, preliminary reconnaissance is the survey or inspection that takes place before decisions are made that affect land allocation for a particular activity. It is the link between land-management planning and project commitment, and most of the critical issues the Forest Service engineer will identify during this process will be site specific.

Preliminary site reconnaissance is an interdisciplinary planning job, during which the engineer and other specialists must determine not only what effects mining will have on Forest Service land, but also what measures must be taken to coordinate minerals activities with other resource uses and with resource protection. While the precise location of mineral deposits probably cannot be determined at this point, general information should be obtainable, based on the geology of the area. Site investigation should provide a better understanding of where arterial and collector roads may best be located, and whether or not short-term facilities[1] will be necessary if mineral exploration occurs. This type of planning is important, because unlike other resource activities on forest lands, the Forest Service does not control when minerals development will take place. Such planning allows time for advance evaluation of impacts before a permit is requested. It also allows consideration of alternative approaches for a project.

What occurs during preliminary site reconnaissance?

During reconnaissance, the engineer and other members of the ID team may investigate such items as terrain, slope, drainage crossings, land ownership, hydrology, vegetation, and stability.

Discussion:

During reconnaissance, the Forest Service engineer, sometimes in conjunction with industry, will consider arterial and collector road

[1] A short-term facility is a road that will cease to exist after the objectives for which it was developed are accomplished. Its useful life is less than 5 years. This term covers all roads on Forest Service lands that were previously called temporary.

location, and prescribe types of surveys, construction control—and in the case of a short-term road—prescribe rehabilitation and reclamation methods. At this point no commitments have been made about leasing, and the engineer is merely investigating whether the land is suitable for minerals development, what the effects of minerals development might be, and whether these effects can be mitigated.

Chapter 2
COMPUTER-AIDED PLANNING TOOLS

Chapter Organizer: Dale Frost

Major Contributors: Dale Frost, David Gibson, Thomas King, Thomas Lehman, M. Douglas Scott

Currently, computer systems are being developed that can be used by land managers, Government regulatory agencies, and mining companies to design mine facilities and plan land reclamation. Methods are being tested for processing surface and subsurface data in a digital form that a computer can quickly manipulate and display. Generally, computer systems have visual display and simulation capabilities which, by using topographic, and subsurface and surface data such as timber type, can depict what a proposed mine development will look like before any actual construction work begins. These computer tools can provide significant planning help for a forest land manager and engineer. This chapter discusses two such processes, LANDFORM and SEAMPLAN, which are being developed by the Forest Service in cooperation with various other organizations.

In addition to these processes, many other computerized techniques are available. They include techniques for traffic-network analysis, land-use evaluation, display systems, and supply-demand analysis. Individuals involved in minerals development should review available computer techniques with forest and regional staff to secure the right tool for the job being conducted.

THE LANDFORM PROCESS

What is LANDFORM?

LANDFORM is an acronym for Land Analysis and Display FOR Management. It is a computer-aided system of planning and designing minerals development and reclamation.

Discussion:

LANDFORM is a series of integrated computer programs designed to take surface and subsurface data gathered in accordance with prescribed criteria, manipulate and perform various calculations on these data, and produce information, plots, and computations that are useful both for land-management planning and for engineering design. The accuracy of the output is directly dependent on the quality and accuracy of the input. The system is designed to provide a statistical expression of how well the digital terrain model prepared as part of this system can interpolate the elevation of independently determined test points. This allows the user to decide if the data file has sufficient resolution for the planned project.

What are the benefits of using LANDFORM?

LANDFORM brings together digital modeling techniques, engineering design programs, and information display techniques into a single, integrated process. This process will help land managers, industry, and the public identify the costs and benefits of a development proposal in a more timely and effective manner.

Discussion:

The use of the digital terrain model with certain of the system programs enables the user to take physical features or characteristics from any map with an established coordinate system and plot them onto other maps or photographs. The programs also generate design quantities from basic input such as horizontal and vertical alignment and section templates.

Some other advantages of using a systematic computer-aided process are:

- Reduction of planning and design costs.
- Ability to examine and evaluate a greater number of alternative actions.
- Ability to provide more comprehensive

plans and designs with more satisfactory consideration of all resources.

- Depiction and simulation of proposed actions making them more easily visualized and understood by planners and the public.

- Improved analysis and coordination of various development operations with resulting efficiency and reduced costs.

How is LANDFORM organized?

LANDFORM is divided into three basic phases: Data Gathering and Organization, Information Display, and Designs and Plans.

Discussion:

Phase I — Data Gathering and Organization. There are various methods used to collect data for the first phase of LANDFORM. In one method, digital models are built using techniques of gathering surface and subsurface data from aerial photography and geologic exploration methods. Terrain data may be gathered in different ways. The Mahan method involves developing a digital terrain model from a stereo pair of aerial photographs. This is produced by digitizing individual points along drainages, ridgelines, and general form lines.

Another method involves using data collected by the U. S. Geological Survey as a byproduct of the agency's orthophoto production process. These data, which are derived from 1:80,000 scale photography, are of intermediate level (40-ft contour) accuracy. This level is suitable for planning where fine resolution is not essential, and would be an inexpensive method of rapidly and economically obtaining data for general forest land-management planning.

Yet another method is collecting data directly from a contour map. The collection process can be done using the principles of the Mahan method or by digitizing along contour lines.

In addition to surface information, subsurface data can be gathered from drill hole logs or by other geological techniques. From these data, subsurface information such as ore bodies, faults, and other geologic structures can be displayed. Both surface and subsurface information can then be interrelated to other resource information for consideration in mine design.

A key requirement of any computer-aided modeling system is the ability to store large quantities of data (the digital model) and provide an efficient means of retrieving selected portions of that data for developing designs or displays. LANDFORM is structured so that all entering data are transformed to a uniform coordinate system. These data are then referenced so that specific information can be readily located without searching the entire data bank.

Phase II — Information Display. During phase two, the visual display puts the data into a form easily understood by the various audiences that will use LANDFORM. Existing and proposed landforms can be portrayed in perspective with basic products such as contour, grid, slope, and aspect. In addition, alternative action designs can be generated and plotted. This would include displaying land lines, pit designs, transportation designs, and waste-disposal areas in the perspective of vertical or oblique photographs as well as in two- and three-dimensional plots.

Phase III — Designs and Plans. In phase three, designs are generated by engineering programs using surface and subsurface digital models. This information can be used for a variety of products, such as computing quantity of overburden or waste material, defining both quantity and quality of mineral deposits, and generating earthwork quantities for alternative transportation facility locations. These outputs are helpful to designers and planners for analyzing specific effects of an action prior to actually starting the action on the ground.

How can LANDFORM be applied on a mining project?

A technology transfer process will get the system and its application to potential users.

Discussion:

In order to transfer the understanding and use of LANDFORM to those who can benefit from it, the process is being documented in two handbooks: The User's and Operator's Manual and the Programmer's Manual (in press). These documents are the framework for a training program that can be directed toward the Forest Service, other Federal and State agencies, and industry.

Further developments and refinements beyond the initial release of the program are antici-

pated. Initial application has been oriented to supporting the decisionmaking process regarding mineral areas. As a result of an increased concern for environmental protection, and resulting legislation, careful and complete planning of mineral development has become mandatory. Comprehensive planning is especially important because mining not only requires a significant investment but also produces rapid and significant changes in the physical, biological, social, and economic structure of a community. Timely decisions are required in order to effectively deal with these changes.

The long-range goal of LANDFORM is to help the land manager, whether State, Federal, or private, do a better and more comprehensive job of planning for development and reclamation. The possibilities of using computer systems for gathering and displaying information can lead to more informed and objective decisions on a wide range of activities involving changes in landform.

What is the current status of LANDFORM?

Most of the programs presently available in LANDFORM have had limited testing and were able to be operated by November 1979. In the future, there undoubtedly will be changes, additions, enhancements, and corrections to the manuals and the programs.

Additional Information:

For further information about the LANDFORM process, contact Thomas King, The LANDFORM Project, Engineering Staff Group, USDA Forest Service, 324 25th St., Ogden, UT 84401.

THE SEAMPLAN PROCESS

What is SEAMPLAN?

SEAMPLAN is a minicomputer-based mine and reclamation system for surface coal mines. The process can be used to plan and design mining operations, as well as to monitor the operations once production is underway.

Discussion:

By integrating programs and research results from a variety of sources, and by utilizing state-of-the-art interactive computer graphics technology, SEAMPLAN enables planners to evolve mine plans to meet stated production and cost objectives, while considering tradeoffs between productivity and environmental protection. This system may also be used as a tool to designate areas unsuitable for mining, and to determine the most feasible postmining land use. The system is capable of expansion as new technology and information pertaining to mining, reclamation, and environmental impacts become available.

How is SEAMPLAN organized?

SEAMPLAN consists of five software modules implemented on a minicomputer. The modules are defined as the data management module, the graphics module, the production analysis module, the reclamation planning module, and the impact analysis module. The data management and graphics modules do not, however, exist as separate entities. Instead, data access and graphic displays are an integral part of the other modules.

Discussion:

The data management module. Basic input to the SEAMPLAN system consists of four main types:

1. Core or drill-hole data, which provide a description of the physical and chemical conditions under which mining might take place. Such information might include the depth of overburden, the depth of coal, and the various qualities and characteristics of each.

2. A second type of information input is related to the production and capital requirements of the operation. Such information might include required tons/yr, minimum required rate of return, and the projected selling price of coal.

3. Restrictions with respect to environmental protection, such as those specified by the law or by management objectives. These restrictions could place constraints on such things as the basic type of mining operation, the method of spoiling overburden, and reclamation methods.

4. Site data, such as climate, soils, and hydrologic conditions. These data would be used to estimate environmental impacts, to develop reclamation strategies, and to plan postmining land use.

After the basic input is fed into the system, a large array of computational and mapping routines is available to the user. Displays of the ge-

ology, stratigraphy, and various properties of the overburden can be made in the form of three-dimensional perspectives, contour plots, fence diagrams, bar charts, and various other graphical modes. The primary purpose of this part of the system is to allow the user to recall, manipulate, and display information to aid in designing the production and reclamation operations of the mine.

The production analysis module. Once the user has obtained the various maps and computational summaries necessary, a mine plan can be developed and analyzed by using the production analysis module. This module consists of three design levels. The mine planning process begins at level two, pit design, because the greatest cost of a Western surface-mining dragline operation is removal of overburden. At this level the user can evaluate a number of stripping techniques and objective functions. After the pit and dragline operations have been designed, the user can employ either level one or three. At level one, all the auxiliary operations that support overburden removal are analyzed. Other operations are specified according to the production rate of the dragline. Included among these operations are topsoil removal, drilling and blasting, coal loading and hauling, coal preparation, reclamation, general support operations, and cash flow analyses and reports. Level three provides a detailed evaluation of the overburden removal operation. For any given location in the mine, mining method, and specified dragline sequence, this level can be employed to perform a swing-by-swing simulation. While such detail may not be required for production planning, it is necessary in order to predict environmental responses.

The reclamation module. The reclamation module, CLAIM, consists of four main product subsystems: FEASI, TECON, OPUSE, and GRADE. The FEASI subsystem evaluates approximately 75 environmental data inputs, and ranks the relative environmental feasibility of returning the area to each of the five main land-use options, which are: cropland, native vegetation, wildlife habitat, recreation, and high human use.

TECON is a system that evaluates the local environmental conditions, then prints a list of recommended reclamation techniques, with costs, for each of the five land-use options. OPUSE combines the results of FEASI and TECON, to produce a ranking of the five land uses from the most optimal choice to the least.

The GRADE program is a part of the TECON subsystem, but also can be operated separately to determine grading costs for both dragline and truck and shovel mines. This system allows the operator to specify the basic mine configuration, as well as describe what the topography should look like after reclamation. Then the program will calculate the total cost/acre for grading. The CLAIM system is designed to interact with the mine production module, so that tradeoffs between reclamation requirements and productivity needs can be made.

The impact analysis module. After the production plan has been specified, this module is used to predict various environmental responses, such as wind and water erosion, characteristics of ground and surface waters, subsidence, and wildlife. If some of these responses are unacceptable, the user can backtrack through the production and reclamation modules and design an alternative plan.

The operations monitoring module. This module can be used to monitor activity once operations have begun. Because features of a particular site may be different than the first projections, the economics of the market may change, equipment and methods may improve, the original plan may need to be modified and updated. This module may also be used by industry and regulatory agencies to review the progress of individual mines, or all mines by ownership and location.

What is the current status of SEAMPLAN?

Most of the programs presently available in SEAMPLAN have had limited testing and were able to be operated by November 1979. In the future, there undoubtedly will be changes, additions, enhancements, and corrections to the programs.

Additional Information:

For more information on SEAMPLAN, contact Edward R. Burroughs, Jr., Forestry Sciences Laboratory, P. O. Box 1376, Bozeman, MT 58715.

Chapter 3
TRANSPORTATION SYSTEMS: PLANNING, DEVELOPMENT, OPERATIONS

Chapter Organizers: William Boley, William Martin

Major Contributors: Robert Hadley, Ira Hatch, Ronald Hayden, William Martin

One of the goals of the Forest Service is to plan, develop, and operate a network of transportation systems on national forest lands that will provide for user safety, convenience, and efficiency, while accomplishing land- and resource-management goals. These transportation systems include roads, trails, railroads, waterways, pipelines, slurry lines, conveyors, tramways, airports, and power transmission lines. The Forest Service engineer is a key person in coordinating these facilities so that they complement each other and form an integrated system that meets the overall goals of the forest plan.

As part of the forest plan, land managers and Forest Service engineers will evaluate the current road system and will identify needed improvements to the forest's arterial and a portion of the collector road systems. Different transportation systems for various land- and resource-management alternatives are also considered. Transportation planning considerations during the forest plan should include, to the extent possible, minerals-management access needs.

Transportation planning must also be done at the project plan level. Project plans, such as mining operating plans, will identify those specific transportation facilities needed to carry out project activities and will examine the relationship of these facilities to the long-range transportation needs established in the forest plan. As an example, at the time an operating plan is filed, the engineer needs to examine such items as road standards, location corridors, maintenance requirements, traffic control, and reclamation procedures. Although roads are generally the prevalent form of facility needed for a project, other types of facilities must also be considered. This chapter looks at transportation systems through three phases: planning, development, and operations. Planning and development will generally be done during premining activities; operations occur during all mining phases.

TRANSPORTATION PLANNING

Why is it difficult for the Forest Service to include minerals management in long-range transportation planning?

Planning for minerals management is difficult because the minerals resources are underground, the extent of the minerals is generally unknown, and the Forest Service doesn't control their development. This is not the case with renewable-resource management, since those resources are visible, are generally quantifiable, and the Forest Service controls them.

Discussion:

Because it is difficult for the Forest Service to predict what transportation facilities will be needed for minerals exploration, development, and operations, Forest Service personnel usually find themselves in the position of having to react to proposed minerals activities. This situation is especially acute at the exploration stage, when road permits are requested on very short notice. Mining companies often can't predict the extent of their operations until some exploration work has taken place. They are also reluctant to divulge proprietary information about the nature and scope of their prospecting intentions and discoveries. Such safeguarding of information prevents the Forest Service from knowing what types of traffic and loads to expect. Thus, road requests must be reviewed in the context of anticipated damage and the potential of the road to serve renewable resources.

What can be done to make access planning for minerals activities easier?

The problems involved in predicting transportation needs for minerals activities can be diminished if the lead time for road permits is increased, the nature and scope of the mineral discovery are known, and the Forest Service has a long-range transportation plan for the area.

Discussion:

Although mining companies hesitate to discuss their prospecting intentions or discoveries, Forest Service geologists who have some knowledge of the nature and scope of planned minerals activities can help the engineer predict the related transportation requirements. Also, if the Forest Service has a long-range transportation plan for the area, a judgment can be made about how well the roads needed for minerals management will complement these planned long-term needs.

What control does the Forest Service have over minerals exploration access?

While the Forest Service generally cannot deny a company access to certain areas when exploring for minerals, it can specify the types (short-term or long-term) and standards of roads the company must use.

Additional Information:

For more information, refer to Section 7730 of the Forest Service Manual and Section 36, Subsection 212 of the Code of Federal Regulations.

What is the best choice for access during minerals exploration?

During minerals exploration, the most desirable choice for access is to utilize an existing road system, even though it may have to be upgraded to accommodate exploration equipment.

Discussion:

Before determining whether an existing road system can be used for exploration activities, the forest engineer will need to know the type of equipment the mining company has, the volume of additional traffic and when it will occur, and the current use of the road. The engineer will need to consider such factors as whether or not the road is open to public use; what type of vehicles presently use it; whether use of the road by the public and other commercial traffic conflict with exploration usage; what traffic control and maintenance levels are necessary; and, if needed, whether materials are available for improving the road surface. When setting the road maintenance level, it will be necessary to determine if the road should be watered, if it should be bladed more frequently than before exploration, and if drainage structures such as culverts will need to be upgraded to support heavier loads.

After exploration, the original maintenance level for the road can once again apply, unless exploration activity has changed the road's use pattern.

What occurs during planning for a mine transportation system?

During planning for a mining transportation system, the forest engineer will review the mine operating plan to see if the proponent gives specific locations for all roads; uses existing roads wherever possible; plans (as much as possible) new access routes on the same locations where the Forest Service plans to develop permanent roads; and uses geometric alignment criteria that are based on the intended standards for these roads.

Discussion:

The land manager must supply the operator with any specific requirements or limitations imposed by the land-management plan. The operator, the land manager, and the U. S. Geological Survey representative must reach agreement on drilling or development locations. In addition, the mining operator should supply information about the type of mineral to be mined, the type of operation (whether the mine will be surface or underground), and the type and location of facilities (roads, railroads, pipelines) required.

The operating plan for the proposed minerals operation should include: (1) a map that shows proposed and existing facilities; and (2) descriptions of their characteristics.

The review of transport and access needs for the mine should include:

- **Location corridor.** Where will the road be built? (Where possible, facilities that were used for exploration should also be used during production.)

• **Functional class.** Will the road be short term or permanent, and if permanent, will it be arterial, collector, or local?

• **Vehicle design.** What kinds of equipment will travel on the road?

• **Traffic volume design.** How much traffic must the road carry? Public, Forest Service, and mining traffic should all be considered.

• **Speed design.** At what speeds will the traffic on this road travel?

• **Use duration.** Will the road be used year-round or just seasonally?

• **Measures to mitigate environmental damage.** Will there be environmental damage, how much, and what can be done to offset any damage?

• **Survey, design, and staking requirements.** What controls are required to assure that the road is completed as planned?

• **Surface type.** Will the road have an asphalt or an aggregate surface?

• **Suitability for public use.** Will the public be able to use the road after the mining company no longer needs it? If so, who will maintain it? If not, how will it be used, or will it be put to bed and reclaimed?

What design standards are used for analyzing transportation facilities?

Two types of design standards are used for analyzing transportation facilities. Geometric standards deal with dimensions such as alignment, grades, widths, sight distances, and clearances. Structural standards apply to such features as thickness, composition of materials, construction methods, and load-carrying capacities.

Discussion:

Selection of design standards must be based on the vehicles or equipment to be used and their operating characteristics. Many of the vehicles used in minerals operations are longer, wider, heavier, and have a longer wheel base than those used for other purposes. These variations must be considered when setting design standards. The requirements of the equipment will generally dictate minimum standards; standards above this minimum should be justified by a formal analysis.

Short-term facilities should be designed so that they can be obliterated after they have served their purpose. Long-term facilities should be designed to serve the projected maximum traffic or use requirements that might occur in the design life.

When must a mining operator reconstruct an existing road on forest lands?

The mining operator must reconstruct existing roads if the additional minerals traffic cannot be accommodated safely and/or if it will cause road damage.

Discussion:

If additional traffic cannot be safely accommodated on an existing road, it might be possible for the mining operator to use the road during nonpeak traffic hours. Another option might be to reconstruct the road, perhaps changing it from a single-lane to a double-lane road. Reconstruction costs will be borne by the operator.

To determine whether reconstruction is needed, several factors should be considered (most of this information must be supplied by the minerals operator):

• User safety.

• Seasonal and daily fluctuation of traffic flow.

• Estimated peak-hour traffic.

• Distribution of vehicles by type and weight.

• Directional distribution of traffic.

• Economics.

TRANSPORTATION DEVELOPMENT

How is a mining-related transportation facility actually developed?

Development of a transportation facility involves survey, design, and construction.

Discussion:

The land manager, based on information supplied by the Forest Service engineer, should specify the survey standards for each facility. The survey standards should be based on land and resource values, design standards, construction specifications and controls, terrain, and costs. The land manager also specifies which method of design will be used. Prior to design, the mining company's engineer should conduct field investigations to obtain the subsurface data necessary for designing stable cut and fill slopes,

adequate foundations, and surface or pavement structures. The types of tests and the methodology used in conducting these tests should be consistent with the nature of the materials and the design situation. The land manager can specify the amount of field investigation and testing required for each facility.

Construction of roads on National Forest System lands is governed by the "Forest Service General Provisions and Standard Specifications for Construction of Roads and Bridges—1979."[2] Some standard specifications exist for other facilities, such as water and sewer lines. Where there are no standard specifications, such as for conveyor systems, project specifications will have to be developed. Drawings and specifications for transportation projects will be reviewed and approved by the land manager based on information received from the engineer. Construction should be monitored to make sure it meets specifications. The land manager is responsible for final inspection and approval of each project.

TRANSPORTATION OPERATIONS

What is the role of the Forest Service during operation of a transportation facility?

The Forest Service is responsible for monitoring, evaluating, regulating, and controlling transportation facilities; administering any cooperative transportation programs and activities; and maintaining certain transportation facilities.

Discussion:

State traffic codes generally apply to Forest Service roads that are open to public travel. In some cases, such as where off-highway loads are allowed, Federal regulations for traffic control and road management apply when State traffic codes are inadequate or inapplicable.

It is necessary to apply for permission to use Forest Service roads for commercial purposes. Road permits may be made conditional on sharing maintenance costs. Mining operators are responsible for maintenance commensurate with their use of Forest Service roads, and they are responsible for *all* maintenance on roads where they have exclusive use through a special-use permit. An approved operating plan is not usually required to use existing Forest Service roads, as long as traffic safety is maintained and hauling does not damage government property or resources. An operator must receive advance permission to use an existing road that has been closed by, or with the approval of, the Forest Service. Permission to use such closed roads may be based on an approved operating plan; if no operating plan is required, a special authorization must be obtained from the Forest Service. After abandonment, all short-term roads must be rehabilitated.

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[2]*Engineering Manual, Section 7720-100. USDA For. Serv.*

Chapter 4
SURFACE FACILITIES FOR MINERALS EXPLORATION AND DEVELOPMENT

Chapter Organizer: William Boley

Major Contributors: Phillip Bursk, William Fiant, Ira Hatch, Omer Humble, David Morris, Dayton Nelson

As a member of the interdisciplinary team, the Forest Service engineer will be involved in determining the effects of minerals exploration and development on forest-system lands. Environmental damage can result not only from exploration methods and equipment, but also from transportation systems and other facilities needed to conduct this activity. Thus, prior to exploration, the engineer and other staff specialists will need to work closely with industry to set standards (when appropriate), establish continuity with on-going and future projects, insure that specific projects meet the Forest Service's long-range goals, and determine appropriate methods and technology to use for each project.

If exploration results in minerals development, the location of the operation can sometimes be influenced or dictated by the land-management agency, depending on the type of mining involved and the laws that control the mineral. Road access can also determine the location of an operation.

When minerals development does occur, one of the Forest Service engineer's functions will be to review the company's operating plan for the design and construction aspects of the operation's surface facilities, and provide the land manager with an assessment. During this process the engineer will work with other government agencies, such as the Mine Safety and Health Administration, the Office of Surface Mining, and the U. S. Geological Survey.

MINERALS EXPLORATION

When a minerals company does exploration work, what activities occur?

During exploration, a minerals company will conduct on-site testing and evaluate data obtained through the use of geology, geochemistry, geophysics, drilling, sampling, shaft sinking, mapping, surveying, and seismic recording. For many of these activities, short-term roads will be necessary, and such roads must be rehabilitated when they are no longer needed. See figures 1 and 2 for examples of exploration equipment.

Discussion:

Minerals exploration activities may vary from relatively simple projects involving no surface disturbance, to complex, high-density programs that disturb 100 percent of the surface land area. These complex programs may take detailed planning and rehabilitation, because, in some cases, exploration can have an even greater impact on the land surface than minerals development.

When minerals exploration takes place on forest lands, what will the major-engineering concerns be?

When a minerals company begins exploration work on forest-system lands, it is important to consider how long the activity will take to complete, the time of year during which the activity will occur, the kinds of equipment the company will use, the facilities it will need, how the equipment and facilities will affect the environment and what rehabilitation measures will be necessary. (See figures 3 and 4 for examples of rehabilitation measures.) The Forest Service engineer has basically the same responsibilities for minerals facilities as he does for other special-use developments.

Discussion:

Standards need to be tailored for each site, based on environmental values that need to be protected, the type of equipment that will be used, and the facilities that will be built.

Figure 1. Three tractor-mounted vibrosis machines gathering seismic data during oil and gas exploration.

Figure 2. Portable and vehicle-mounted drills used during oil and gas exploration.

Figure 3. A dry, wildcat hole being restored. Dozer is leveling the site and filling in the mud pit. The drill hole is plugged and monumented.

Figure 4. Wildcat drill site after the first catch of native grass. Only the drill hole shows.

What types of facilities may be constructed during exploration?

Facilities connected with exploration activities are usually drill pads, pit tanks, camp sites, water facilities, and transportation systems.

Discussion:

Each of these facilities should be designed and constructed to avoid permanent adverse impacts on the environment. The engineer should also check with local zoning and health authorities, to see if any special requirements, such as a septic tank, need to be included in the project plans. If a company uses existing roads for exploration activities, it will be important to find out the types of vehicles the company will be operating, what kind of maintenance and traffic control the road will require, and who will fund and do the maintenance. (For a more detailed discussion on roads for minerals exploration, see chapter 3.)

Additional Information:

For more information on oil and gas exploration and production, refer to:

"A Primer of Oil Well Drilling," The University of Texas at Austin. Third Edition, 1970.

"Primer of Oil and Gas Production," Production Department, American Petroleum Institute, 300 Currigan Tower, Dallas, TX 75201.

MINERALS DEVELOPMENT

What is the role of the Forest Service in relation to minerals development facilities?

The Forest Service should monitor the design and construction of the facilities related to minerals development, to make sure these facilities conform to the company's operating plan. Activities should be coordinated with other appropriate agencies such as the Office of Surface Mining and the U. S. Geological Survey, or the equivalent State or Federal reclamation agency to avoid duplicating efforts. Monitoring during operations should insure appropriate construction of new or expanded facilities, and maintenance of existing facilities.

Discussion:

The layout and design of minerals development facilities is essentially a premining activity.

Figure 5. Typical surface coal-mine layout with a generating plant, transportation facilities, and a town.

Eighty or ninety percent of the money spent on facilities will be spent before any ore is mined. The remainder will be spent during the life of the operation for maintenance and for new facilities needed for expansion.

Construction standards for surface facilities are often prescribed by law. The Mine Safety and Health Administration, for example, regulates the design of bathhouses and magazines. (See figures 5-7 for examples of surface facilities related to mining.)

Detailed design and planning for surface facilities is usually accomplished either by a company's in-house engineer or by consulting engineers. Construction is generally done by subcontractors, except for some large firms that maintain their own construction capabilities. The responsibility for maintaining surface facilities rests with the company.

What determines the facilities that will be included in a minerals operation?

Surface facilities for a minerals operation are determined by the geometry of the deposit, topography, water availability, size of the operation, climate, location of the transportation system, the mining method, and beneficiation requirements.

Discussion:

The geometry of the deposit determines whether a mine will be surface or underground, which is the first step in assessing what surface facilities are required. Rugged topography, such as that associated with much of the underground coal mining on forest-system lands in the West, has a profound effect on the layout of the facilities. In many cases, topography will dictate where the facilities will be located. As the topography becomes more gentle, greater flexibility exists in site selection.

Water is necessary for dust control, fire prevention, personal hygiene, and for ore preparation and mining itself. Pump houses, reservoirs, and pipelines other than those related to oil and gas are all affected by water availability. The size of the operation directly affects the size of facilities such as the office, the bathhouse, and the warehouse. Climate is also a factor. In some cases a severe winter climate might make it necessary to build air-heating units into the mine ventilation system. Harsh weather might also

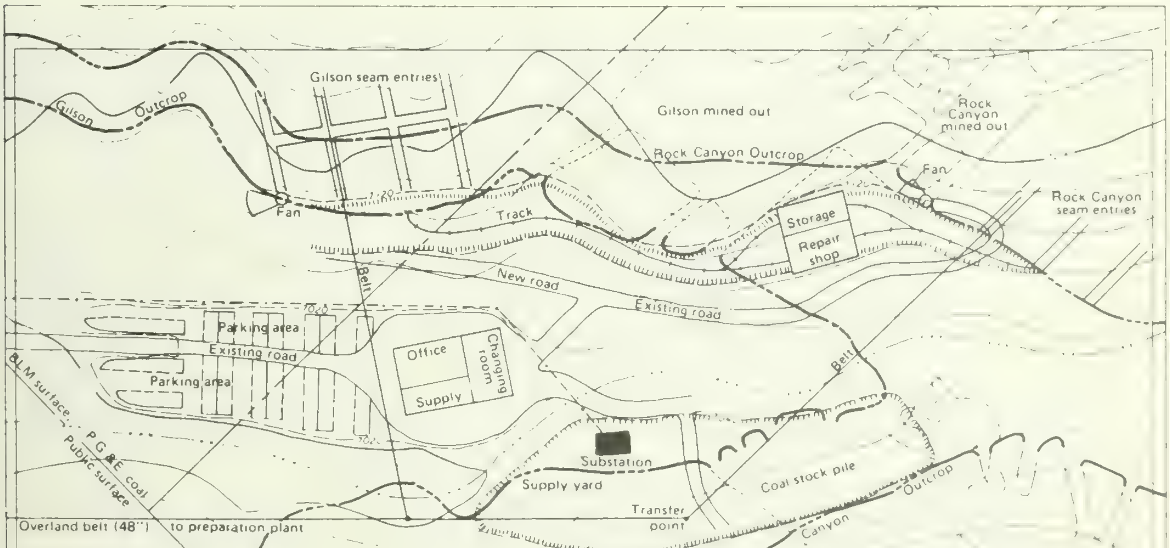

Figure 6. Surface facility layout of a typical Utah underground coal mine. (David Morris, John T. Boyd Co)

cause a surface mining operation to maintain enclosed bays to protect equipment not in use.

In coal operations, rail haulage is an important consideration. Unit-train loadout facilities require a large amount of space in the form of either a rail loop or a dead-end spur.

The mining method will affect the size and design of supply storage facilities, shops, and the electrical distribution system. Mineral beneficiation influences the actual facilities associated with the plant, the water supply, disposal system, and the design of the water disposal facilities.

Do most mineral developments have the same types of facilities?

Some facilities are common to both surface and underground mines, as well as oil and gas operations. Other facilities, however, are generally associated with one method of mining or the other, and some facilities are unique to oil and gas developments.

Discussion:

Some facilities generally associated with all minerals developments are:

- **Essential.** Office, bathhouse/changehouse, powerlines, electrical substation, parking area, mineral storage area, loading facility, fresh water supply/storage, equipment supply/storage area, drainage and sedimentation system (includes ponds, dams), access road, topsoil stockpile, mineral beneficiation plant, refuse disposal area, rotary breaker/crushing station, explosives storage, warehouse/shop, laboratory, water treatment plant, haul roads, railroad/truck scales, sewage-treatment plant.
- **Optional.** Diesel generator, conveyor belt system, guard house, visitors' center, air strip, helicopter pad, training center, housing/new town.

Some facilities generally associated with an underground mine are: fanhouse, shaft with headframe, rock dump bin, rock dust storage, degasification plant for coal mining.

Some facilities generally associated with a surface mine are: diesel fuel storage, truck wash, tire storage, oil and grease house, equipment parking area, truck dump, spoils dumps, bridges, culverts, reclamation test plots.

Some facilities generally associated with an oil and gas development are: crushers, screens, flotation units, storage tanks, drilling rigs, heater units, separators, containment dikes, salt-water injection pipelines.

Figure 7. Typical surface facilities of a phosphate beneficiation plant.

Chapter 5
GEOTECHNICAL ENGINEERING AND MINING PRACTICES

Chapter Organizer: Bruce Vandre

Major Contributors: Loren Anderson, Bruce Vandre

The practice of geotechnical engineering essentially involves the design aspects of slope stability, settlement, earth pressures, bearing capacity, seepage control, and erosion. These factors are major considerations when developing a mine because some geotechnical concerns—for example, mine-waste dumps—have a poor history in terms of stability and environmental effects. Moreover, the consequences of slope failure are not only highly visible, they can also be catastrophic.

This chapter deals with the total geotechnical engineering role from the standpoints of both industry and the Forest Service. Although the geotechnical engineer working for industry will prepare the actual plan for a minerals development, the Forest Service engineer will review a company's operating plan and advise the land manager of the geotechnical considerations, as well as propose design guidelines. The Forest Service alone will not be responsible for all geotechnical review, but will interact with other agencies such as the Mine Safety and Health Administration, the Office of Surface Mining, the U. S. Bureau of Mines, and the U. S. Geological Survey.

GEOTECHNICAL ENGINEERING

What is the geotechnical engineer's main job?

A major part of the geotechnical engineer's job is to determine the physical engineering properties of earth materials.

Discussion:

Unlike the structural engineer, who can specify the compressive strength of concrete and the stress/strain properties of steel, the geotechnical engineer must determine the shear strength and other important physical properties of soil and rock. The geotechnical engineer must also decide how these properties change with time, with loading conditions, with moisture conditions, and with the method of compaction. All of these factors will significantly affect the shear strength, the compressibility, and the permeability of the soil. Consequently, after the site investigation and laboratory testing program, experience and judgment are major factors in determining the engineering properties of soil and rock.

What types of disciplines does geotechnical engineering encompass?

Geotechnical engineering is concerned with geology, soil mechanics, and rock mechanics.

Discussion:

Solving difficult geotechnical engineering problems often requires a team approach, involving interaction between engineering geologists and engineers specializing in soil mechanics and/or rock mechanics. In addition to understanding the basic principles of these disciplines, a knowledge of precedents is essential for the successful practice of geotechnical engineering.

What kinds of evaluations and recommendations do geotechnical engineers make?

Geotechnical engineers evaluate slope stability, settlement, earth pressures, bearing capacity, and seepage and erosion, and then recommend design criteria considering the specified performance requirements.

Discussion:

Geotechnical engineers are concerned with the stability of natural and man-made slopes; the settlement of buildings and earth embankments; earth pressures in the design of retaining struc-

tures; bearing capacity in foundation design; seepage control in dam construction; and groundwater movement and erosion from highway embankments, dam surfaces, and spoils dumps. Geotechnical recommendations must consider such specific design or performance requirements as a minimum degree of safety against shear failure or a limiting structural deformation. These requirements may be dictated by structural engineering, hydraulic engineering, economics, policy, or even convention. Conventional or standard safety factors against shear failure are frequently used in foundation design and the design of earth-dam-embankment slopes.

What does the geotechnical engineering process entail?

The geotechnical engineering approach is to: Define the project concept; perform project site reconnaissance; develop a working hypothesis of subsurface conditions; test the hypothesis through field investigation and laboratory tests; develop a model for analysis; evaluate alternatives; make specific recommendations; prepare plans and specifications; provide construction inspection and consultation; and obtain performance feedback.

Discussion:

After the geotechnical engineer working with industry determines the purpose of the subsurface investigation, the next step in the process is project site reconnaissance. This involves a trip to the field to look over the project site, as well as researching any geologic or subsurface investigations that have already been done for the area. On the basis of this information, the engineer will develop a working hypothesis of subsurface conditions, in order to plan the subsurface investigation in terms of the number and type of borings to make, what kind of equipment to use, what kinds of samples to take and how many, and what kind of laboratory tests to run.

Because field conditions generally indicate a nonhomogenous condition with many minute strata of various soil types, it is necessary to develop a simplified model for analysis. After the model has been analyzed, the geotechnical engineer will evaluate the alternatives, including economic factors, and make specific recommendations. The job of the geotechnical engineer in industry should not stop here; he should also be involved in preparing plans and specifications, and in providing construction inspection and consultation. In order to evaluate the adequacy of recommendations and designs, performance feedback should be obtained from all projects—not just those involved in failures.

How can geotechnical engineering be applied to mining?

Geotechnical engineering is applied to mining primarily in the design of excavation slopes, waste embankments, and tailings dams.

Discussion:

Applying geotechnical engineering to mining is essentially using established technology rather than developing new technology, since the methods of geotechnical investigation and analysis used in highway or dam design can also be applied to mine design. Design considerations such as slope safety or construction methods, however, will frequently differ between highways or dams and mines.

When planning and designing mine-waste embankments, abandonment is an important consideration, because mine embankments should be maintenance free at this stage. While highway embankments and dams should also require minimum or no maintenance, the opportunity for maintenance does exist.

MINING PRACTICES

What is the key relationship of geotechnical engineering to the economics of surface mining?

A prerequisite for understanding surface-mining economics is knowledge of the stripping ratio (the number of units of unpayable material that must be mined to expose one unit of ore).

Discussion:

One specific stripping ratio is the break-even stripping ratio. It is determined by forming an equation that contains the recoverable value/ton of ore, minus production costs/ton of ore, divided by the stripping costs. An economic stripping ratio is determined by subtracting desired profits as well as production costs.

A point may be reached where the cost of stripping makes surface mining more expensive

than underground mining. Generally, geotechnical engineering decisions greatly influence the stripping costs, which vary with different minerals. For example, the stripping ratio for phosphate is about 6 yd^3 of waste for 1 yd^3 of ore. For coal, particularly when using excavating equipment with capacities of 180-220 yd^3/pass, the possible economic stripping ratio might be as high as 20-40 yd^3 of overburden per yd^3 of ore. With copper, a common economic stripping ratio would be about 2 yd^3 of overburden for 1 yd^3 of ore. These variations in stripping ratios are explained by the differences in commodity prices, ore grades, and mining methods.

What geotechnical factors influence the selection of surface-mining methods?

The selection of surface-mining methods is controlled by surface topography, the geometric delineation of ore or mineral deposits, and environmental considerations. The first two items determine the stripping ratio.

Discussion:

With flat terrain and flat, thin deposits, access is gained with a box cut, and continued with succeeding parallel cuts. The overburden is cast to the side previously excavated. The dimensions of the excavation slot are primarily determined by the reach and capabilities of the excavating equipment.

Steep terrain, but flat, thin deposits, require a contour strip mine—that is, starting with a bench and excavating it around the hill. The cutoff for mining is determined by the economic stripping ratio, which determines the height of the high wall. Historically, with this method, overburden was disposed of either by pushing it off to the side in piles, by pushing it off parallel to the existing slope, or, sometimes, by pushing it off at a flatter slope. Now, because of environmental concerns, the mining company tries to control spillage from excavation, so in the initial box cut a berm is left to prevent material from spilling over the side. Contour stripping can also be used if the minerals occur in multiseams.

With steep terrain and thin deposits that are fairly close to the ground surface, a method called mountain-top removal may be used. Again, access is gained with a box cut. The first material excavated from the box cut generally has to be disposed of at a different location, possibly as valley fill. After the initial cut the overburden is placed as backfill in the mined-out area. Additional offsite disposal of overburden is required because of the swell in volume between the original ground and the fill. With this method there is no high wall to reclaim.

Thin, flat deposits and strip mining are characteristic of coal mining. Other types of deposits that are surface mined generally fall into the category of open-pit mining. Usually open-pit mining is circular in plan and involves steeply dipping or thick deposits, which are excavated in benches, both for stability and for access. In deep excavations, such as in copper mining, knowing the slope stability from geotechnical analysis can be very important economically, because a difference of 1 or 2 degrees in the slope could mean a considerable difference in stripping volume.

Additional Information:

For more information about geotechnical aspects of mining, refer to "Procedures Recommended for Overburden and Hydrologic Studies of Surface Mines, Final Report, Part I, SEAM Thunder Basin Study," (Draft), by James Barrett, Paul Deutsch, Frank G. Ethridge, William T. Franklin, Robert D. Heil, David B. McWhorter, and Daniel Youngberg. Colo. State Univ. and USDA For. Serv., Douglas, Wyo. December 1978.

Chapter 6
MASS STABILITY AND MINING

Chapter Organizer: Bruce Vandre

Major Contributors: Michal Bukovansky, Richard Dunrud, Frederick Thompson, Roy Soderberg, Bruce Vandre

In mine design, one of the geotechnical engineer's prime concerns is mass stability as it relates to rock slopes, waste-disposal embankments, tailings areas, and subsidence in underground mines. Mass stability is critical to the minerals company from an economic standpoint. For example, when excavating an open-pit or a strip mine, the mining engineer will try to make the slopes as steep as possible without incurring slope failure, because one degree of difference in height could mean a significant difference in excavation costs. Steepening the slope embankments can also frequently reduce costs for waste disposal; however, slope failures can damage adjacent facilities.

Mass stability is also critical to the Forest Service, but for different reasons. Slope failures in mining can cause severe environmental damage, as well as pose a threat to human life.

EXCAVATION AND SURFACE MINING

In the preliminary design stage, what decisions will a mining company make?

At this stage, mining companies will decide what mining method to use, the approximate steepness of the slopes, and make basic decisions on benches and haulage roads.

Discussion:

At this point, the mining company will decide whether or not to use open-pit or strip mining, as well as the shape of the mine. The company will also develop a working idea of slope steepness, since this factor will make an important difference economically.

What should occur during the mining company's geotechnical investigation?

The mining company's geotechnical engineer, generally an outside consultant, will do mapping, drilling, and testing.

Discussion:

The geotechnical consultant will begin the investigation by mapping outcrops, testing the types of rocks and soils in the area, and drilling to learn the properties of the overburden for construction of the plant and tailings area. The geotechnical engineer will also keep logs of geophysical tests to verify the composition of the rocks and soils, and, if ground water is present, will install observation wells. Testing will then be conducted in order to estimate the physical properties of the rocks and soils.

What is a stability safety factor?

Essentially, a safety factor is a ratio of resisting forces to driving forces. Several common methods can be used to calculate a safety factor, and thus obtain some numerical index of stability.

Discussion:

If the safety factor is greater than one, the resisting forces are larger than the driving forces and the slope or slide is stable. If the safety factor is just equal to one, equilibrium exists. If the safety factor is less than one, the resisting forces are smaller than the driving forces, and the slope or slide is unstable and will probably move. Simple rock-slope design charts are available to help evaluate safety factors.

Additional Information:

For more information on safety factors, refer to "Rock Slope Engineering," by E. Hoek and J. N. Bray. Institute of Mining and Metallurgy, London, 1974.

Are any risks involved in slope design?

Yes, uncertainty exists about the reliability of the stability analysis. In soil and rock me-

chanics, there is no way to exactly determine physical properties.

Discussion:

Theoretically, if the safety factor is equal to one, the slope should be stable. Because of uncertainties in data, analysis, and knowledge of geologic conditions, however, the geotechnical engineer uses safety factors greater than 1.0 for design. For civil engineering structures, such as highway cuts, the safety factor usually starts at 1.5 and can go to 2.0 and higher. The mining engineer, however, cannot afford to excavate slopes that appear highly safe, because the costs of excavation would be too great. Economically, it may be advantageous to risk the chance of a small slide.

What are the main types of rock-slope failures?

In rock, there are three main types of slope failures: planar failures, curved failures, and combined failures.

Discussion:

Planar failures happen along planes of weakness, such as a fault, joint, or bedding surface, and typically occur in hardrock materials. Curved failures occur in rock that is weathered and has comparatively uniform strength. Combined failures, which usually occur in horizontally bedded deposits, happen most often in coal and uranium mining.

How can slides be stabilized?

Slides can be stabilized by excavating the slope entirely; excavating the upper portion or loading the lower portion; or installing drainage, buttresses, piles, retaining walls, or anchors.

Discussion:

Whan an open-pit slope fails, one solution is to excavate the entire slide. If the slide is large in size, it may be feasible to excavate only the upper portion, thus decreasing the magnitude of the driving forces. Stability can sometimes be achieved by loading the lower portion of the slide and increasing the magnitude of the resisting forces. Another possibility is to combine both methods and excavate the upper portion of the slide and load the lower portion.

Most slides are related to ground or surface water; therefore, if the water is removed there is a good chance that the slide will stabilize. One of the most popular and economical ways to achieve this in rock is to install horizontal drains. Drainage lowers the ground-water level to a safe position behind the slope of the open pit, and with horizontal drains, drainage is accomplished by gravity. The miner excavates individual benches, and installs a series of horizontal drains, which are inclined holes lined with casing. This is usually done on several levels. The water is carried away from the pit, the walls are dry, and there is a good chance that the slide will stabilize. To monitor the effectiveness of the drainage system, piezometers should be installed. Drainage prior to excavation will generally result in steeper design slopes. Tunnels can also serve as drains, and are used in a number of large, open-pit hardrock mines.

Buttresses, piles, and retaining walls and anchors, also increase the resisting forces and stabilize slides, but these methods are not widely used in open-pit mining.

How can stability problems be detected and quantified?

A good method of detecting and quantifying stability problems is proper use of instrumentation and monitoring.

Discussion:

The company's geotechnical engineer will usually ask the mining company to install a means of monitoring a slope and measuring deformations. The method used may be as simple as surveying. Other possible methods are:

- A shear strip, which is installed in a vertical hole and shears off if the slide moves. With a simple electronic readout, the depth of the failure plane can be estimated.
- A tiltmeter, which measures ground-surface inclination. It is set on the crest of the benches of the pit, and should be checked at least once a month. If the slope is moving, the inclination measurement will change.
- An inclinometer, which measures changes of inclination in a vertical hole.
- An extensometer, which can be used to measure deformation changes in either vertical or horizontal holes.

MINE-WASTE DISPOSAL EMBANKMENTS

What is a mine-waste dump?

A mine-waste dump is a waste-disposal embankment consisting of earth and rock. These embankments, which are usually located on side hills or in valleys, are not water-impounding structures.

Discussion:

Mine-waste disposal embankments generally have little utility in themselves—they are designed primarily to avoid adverse impacts on the environment. The stability and general performance of these dumps should accommodate reclamation and enable future land use compatible with the surrounding area. These embankments should not endanger life, property, or natural resources. Upon abandonment, these embankments should be maintenance free.

Historically, how have mine-waste embankments performed?

Mine-waste embankments have a history of poor performance. It is estimated that 10 to 20 percent of the mine-waste embankments in the United States and Canada have experienced significant slope-stability problems.

Discussion:

Landslides shoot tongues of debris into streams and onto adjacent lands that otherwise would remain untouched by the direct influence of mining. Slope failures also disrupt the vegetative cover established on reclaimed slopes and increase the erosion potential. Another major problem common to waste embankments is settlement. Cracks in the embankment surface occur and massive sections drop. Surface water drainage is disrupted and the embankment stability may become threatened. Settlement can make land unsuitable for use as pasturage or for cultural development. Waste embankments can also change water quality and disrupt flow patterns. With coal waste there is the added concern of fire from spontaneous combustion. Many of these embankment problems occur 10 to 20 years or more after construction. Most of the waste embankments that have failed in the past, however, have not been engineered according to geotechnical practice.

What types of slope failures are common for waste embankments?

Common types of waste-embankment slope failures are curved-arc failures, shallow flow slides and foundation failures.

Discussion:

- **Curved-arc failures.** Damage is usually limited to the immediate slope area. Warning signs of these failures are tension cracks at the top of the slope and bulging at the toe. Common causes of curved-arc failures are: The embankment height may be too great or the slope ratio may be too steep for the soil shear strength; the toe of the slope is either undercut or it becomes saturated.
- **Shallow flow slides.** These occur during heavy rainfalls or high snowmelt, and their depth is commonly less than 5 ft. Shallow flow slides are highly fluid and mobile, and often disrupt areas below the slope. They may occur without warning, cause erosion, disturb vegetation, and hinder reclamation activities.
- **Foundation failures.** These occur when the slope wedge moves out along weak foundation soils. The most severe damage is to the immediate slope vicinity. Foundation failures generally are caused by the end-dumping method of fill placement, which rapidly loads the foundation soils. Foundation failure is progressive in the direction of dumping and may extend beyond the planned limits of the embankment.

What are important site-selection considerations for waste embankments?

The location of a mine-waste embankment is determined primarily by economics, topography, foundation conditions, and future ore reserves.

Discussion:

From an economic standpoint, the shorter the haul distance, and the closer the top of the waste embankment to the excavation elevation, the cheaper the operating costs will be. Thus, there is a strong economic motivation to locate the waste embankment as near to the excavation as possible.

Flat topography is also desirable for waste-embankment placement, because a flat surface

reduces stability problems and provides greater storage capacity for fill material. Generally, when fill material is placed on a slope greater than 20 degrees (35 percent or 3:1), the foundation and preparation requirements become critical. Embankments placed on slopes steeper than 27 degrees (50 percent or 2:1) frequently are unstable.

The presence of cohesive soils and shallow ground water in the foundation may limit the embankment height or restrict the placement method to thin layers. Also, to safeguard stability, drainage measures within the embankment will be required at ground-water discharge locations. Finally, it is important not to cover up future reserves, because what is not mineable ore today could be mineable tomorrow.

What steps are usually involved in the design of waste embankments?

Usually the procedure for design will involve:

- *Making a field reconnaissance of the general site area.*
- *Making a preliminary layout and comparing the areal extent, height, and economics of alternative disposal locations capable of storing the intended mine output of waste solids.*
- *Selecting the most promising site, making a geologic appraisal, and establishing a program of foundation and materials investigation.*
- *Analyzing surface-water diversion requirements.*
- *Analyzing embankment geometry requirements.*
- *Analyzing internal drainage requirements.*
- *Preparing construction drawings and specifications that identify placement procedures.*
- *Verifying embankment material properties used for design during construction.*

Are waste embankments instrumented and monitored like mine excavations?

Generally, the same methods of instrumentation and monitoring used for excavation slopes also apply to waste embankments; however, less monitoring is done for embankments.

Discussion:

Embankments usually have higher design safety factors than excavation slopes, thus their performance is less questionable. For monitoring information to be useful, adverse performance needs to be detected during embankment construction, because remedial measures become difficult after construction is completed. Embankment foundations may be instrumental to control filling rates.

Additional Information:

For more information on waste embankments refer to:

"Recommended Bibliography on Geotechnical Practice for the Design of Non-Water Impounding Solid Waste Mine Dumps," by Bruce C. Vandre. USDA For. Serv., Intermt. Reg. Off. Rep., February, 1979. Ogden, Utah.

TAILINGS DAMS AND IMPOUNDMENTS

What should be considered when choosing tailings sites?

Tailings sites are waste-disposal areas for the residue that remains after a mineral or ore has been processed at a mill. When choosing tailings sites it is important to consider whether the mine will be underground or open pit, what the daily mill tonnage will be, and what environmental impacts may occur on the site.

Discussion:

During site exploration the engineer must make detailed topographic maps, determine the geology of the potential tailings site, core drill for potential economic mineralization in the pond area, and map the surface soil conditions. The engineer must also determine the strength of the foundation; map potential borrow areas for dam building and sample the soil for physical properties; determine the depth to ground water, the number of springs in the area, and the existence of buried talus slopes that could pipe water through the dam; and measure the drainage area above the tailings site.

If the mine is underground, it will be necessary to determine whether any of the tailings will be used for underground fill, leaving the finer material to be impounded in the pond. The size of the tailings area is then determined by the daily mill tonnage minus this fill material. About 35 acres should be allowed for each

1,000 tons of daily capacity. The area should also be divided into two separate ponds for safety and ease of handling.

If there are several possible sites, the one with the least potential environmental effects should be chosen, such as an area hidden from main roads or nearby communities by trees or mountains. While every effort should be made to keep dust from blowing off the tailings area, this does occur, and thus should be a consideration during site selection.

What can be done to minimize environmental impacts from the tailings area?

To minimize environmental impacts, surface runoff from large areas above the tailings site should be diverted around, rather than through, the tailings pond and water-reclaim system. All the water that goes into the tailings pond should be held in a closed system and sent to the mill's reclaim-water reservoir for reuse. The starter dike, which is constructed of borrow material, should be planted with trees and grass as soon as possible.

Discussion:

Some rain and snow will naturally enter the tailings pond, and should be treated before being returned to natural drainage. A diversion ditch could greatly reduce the amount of water needing treatment, and is also a safety feature that could prevent the dam's overtopping.

Drainage from beneath the tailings pond usually goes back to the mill's reclaim-water reservoir. All water going into the tailings pond, such as slurry water, precipitation, mine drainage, and surface drainage should be contained in a closed system and sent to the mill for reuse. Any surplus should be treated, if necessary, and returned to drainage.

Usually the starter dike is easy to revegetate, except in arid areas where irrigation is necessary. The tailings alone are more difficult to replant, because they require more care, fertilizer, and moisture than natural soil does. Some tailings that are high in sulfides oxidize and become so acidic that they are impossible to vegetate unless a foot or more of topsoil is placed on the tailings after mining is completed. Sulfide tailings are possibly the most difficult material to reclaim because soil cover is generally unavailable and even when obtainable, placement costs are high.

What are the various types of tailings dams?

Basically there are two types of tailings dams: the water-reservoir type of dam used for toxic materials, such as cyanide from a gold mill; and common tailings dams, which have many variations. The design of a common tailings dam will be determined by the physical properties of the material being impounded.

Discussion:

The design of a tailings area will be influenced by tonnage, screen analysis, pulp density of the pond, site geology, hydrology, soil classification and physical properties, soil permeabilities, and tailings mineralogy. Tailings ponds should be designed so that all water can be reclaimed. It will be important for the engineer to carefully review the tailings-site design plans. Many mining companies hire outside consultants to design their tailings areas, but some consulting firms are designing tailings areas without previous experience in this field.

When are drains for the bottom of tailings ponds required?

Whether or not drains are necessary on the bottom of a tailings pond is determined by the purpose and nature of the pond and the geology of the area.

Discussion:

When drains are required on the bottom of a tailings pond, it is a good practice to cover them completely with cyclone underflow if the sand produced is clean. (A cyclone is a machine that spins water, removes coarse material, and then sends both the fines and the water upstream.) This sand should be spigoted off the starter dam at its natural slope, since this slope will be steeper than the slope of the unclassified tailings (fig. 8). Thus, when the tailings are placed in the pond, slime will not settle on top of the drains and clog them. Clean sand from a cyclone is attainable only when a relatively low pulp density (small amounts of solids to large amounts of water) is fed to the cyclone.

What controls the safety factor in tailings ponds?

The safety factor for tailings ponds is primarily controlled by the phreatic water line,

which is the top of the free-water surface within the body of a dam or tailings embankment.

Discussion:

The static safety factor, or the safety factor when conditions produce no sudden jarring movements, should be 1.5 during operation of the tailings pond and higher after the pond has been abandoned for a few years and the water pool has been lowered or eliminated. If the water in the embankments is kept low, the downstream slope kept flat (3:1 overall maximum), and the dike and beach compacted above critical density so that liquefaction does not take place, the safety factor should be 1.5 or higher. Constructing the downstream face at a 4:1 (25 percent or 14^{o}) slope will increase the safety factor and will also help with reclamation, since plants take root and hold the soil much more easily on flatter slopes.

How is construction control for a tailings site achieved?

During construction, a competent inspector, either a mining company employee or a company consultant, should be on the job full-time to make sure that all construction is carried out according to design.

Discussion:

The inspector should make sure that:

- The dam foundation and the drain area are cleared of all vegetation, peat bogs, and unstable soil.
- The foundation is compacted and prepared.
- Either pipe drains with gravel or protective filter cloths or blanket or strip drains with adequate clean gravel and protective filters are installed.
- Borrow is properly placed: coarser, more pervious material on the downstream side, and

Figure 8. Spigoting around periphery of tailings embankment. (Roy L. Soderberg, U. S. Bureau of Mines)

finer, more impervious material on the upstream side.

- Proper moisture for optimum compaction is available, and laboratory facilities are available to check for moisture and density control.
- There is special compaction through the starter dam for pipes with seep-rings.

What types of instrumentation and monitoring are common for tailings dams?

Two types of piezometers are recommended for monitoring tailings dams—the open well and the pneumatic. The open-well piezometer is the most common, is least expensive, lasts the longest, and is the easiest to read. One disadvantage is that it has a slow response time when used in low-permeability materials such as clay.

Discussion:

Piezometers are necessary to measure the effectiveness of the drains to insure that water is not building up behind the starter dam. High water indicates the drains are not functioning properly, and corrective measures must be taken to prevent potential instability.

With open-well piezometers, if an increase in head occurs the water in the well must fill the entire tube to that height to register the true head. The pneumatic piezometer registers pressure only, so the response time is nearly instantaneous. In high-permeability areas, such as coarse beach sands, open-well piezometers should register the response with only a short lag time.

Pneumatic piezometers should be placed beneath the starter-dam foundation and just upstream from the upstream toe of the starter dam. If a hollow stem auger is available, it might be easier to place the piezometers after the starter dam is completed, which will protect the lines from damage during construction. At the same time, open-well piezometers should be placed by each pneumatic piezometer, and could be placed in the same hole. This protects against the failure of either one. Pneumatic piezometers can be placed on the natural soil upstream from the toe with the lead lines up beside the header pipe for protection. After water in the dam is high enough, an open well can be placed beside each of the pneumatics.

Open wells should be placed on the downstream face periodically as the height increases, to continuously monitor the water. The water depth should be measured monthly and plotted on a cross-section of the dam to see if it conforms to design plans.

When a dam reaches 100 ft or more, a slope-indicator casing can be placed in the dam to measure movement. Measurements should be made several times a year. Monuments can also be placed on the berm in a line of site to measure both horizontal and vertical movement. Some movement is inevitable, but a stable embankment will have only a small and steady movement.

How is reclaim water within the pond controlled?

Reclaim water is controlled through the use of decant lines and towers, barge pumps, movable wheel-mounted pumps, and siphons (fig. 9).

Discussion:

The decant line for a small operation can be a simple 10-inch, Schedule 40 steel pipe, which is laid on top of the ground from below the starter dam to the upstream side, to the clear-water pool. As the height of the dam increases, the line is extended to keep it in the clear water.

In larger operations, reinforced concrete decant lines should be designed to withstand the total weight of the sand above the lines. Decants remove water from the pond even though a rainstorm might cause power failure for several days. Even if the water overflows the spillway of the holding pond below the tailings dam, this is preferable to overtopping the tailings dam and washing tailings into the watershed.

Towers should be reinforced concrete and can be freestanding, or, if the area is steep, they can incline along the side of the valley. There is some danger that freestanding towers could be pushed over by a subsurface slide of slime or large ice sheets.

Under proper conditions, barge pumps are less expensive to build and operate than decant lines. It is difficult, however, to keep the barge out of the mud when the pond is in a flat area and the tailings are very fine. Also, the clear-water pool tends to be shallow, causing the pump to suck up slimes. In steep terrain, with coarser material, the barge pump is ideal. Then the water pool is generally deeper, and as the dam height increases, the pumping head de-

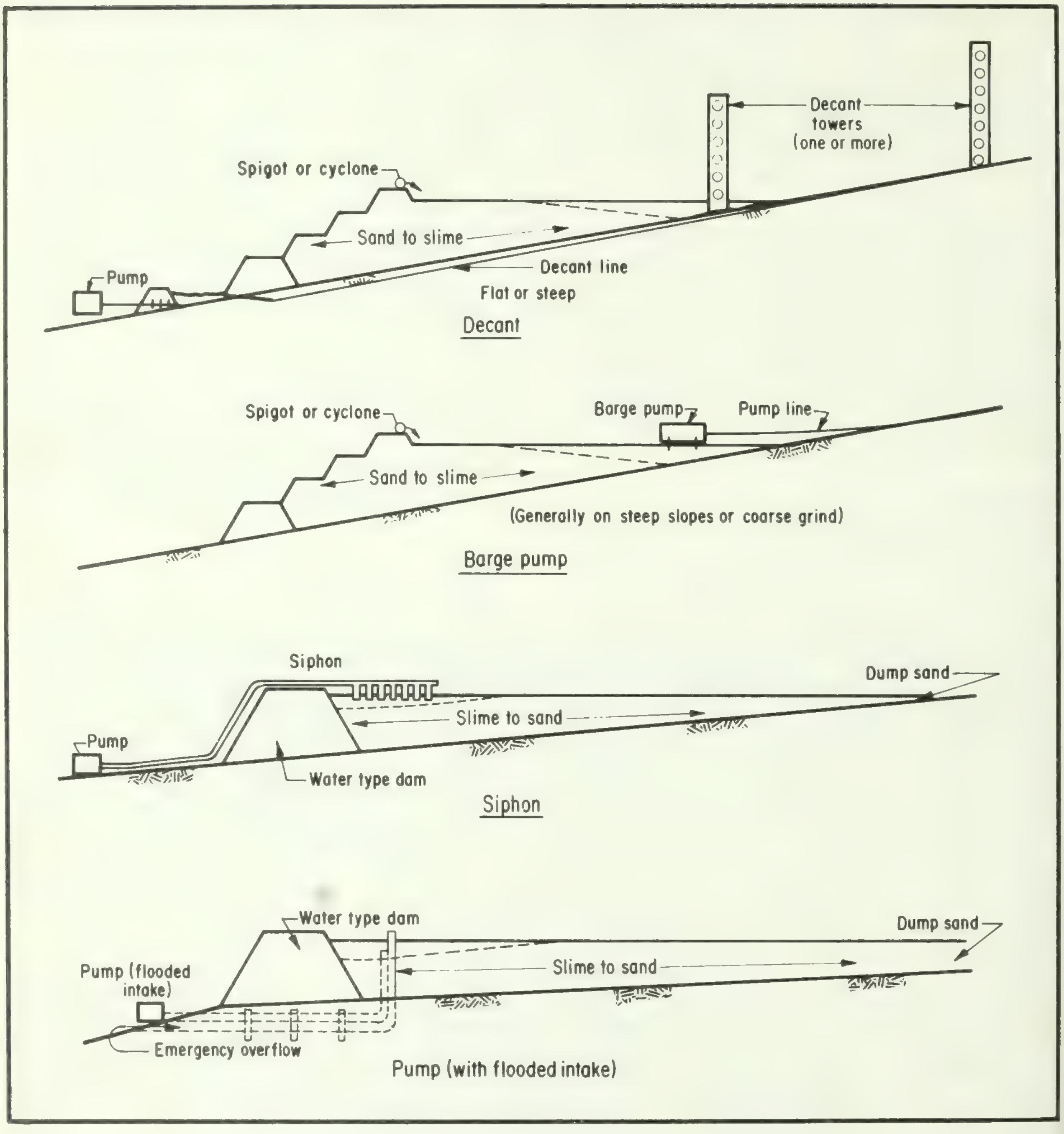

Figure 9. Schematic of decant, barge pump, siphon, and pump with flooded intake. (Roy L. Soderberg, U. S. Bureau of Mines)

creases, thereby using less power. The disadvantage is that in the case of a severe rainstorm and a power failure, the tailings pond might overtop if it cannot retain all the flood water. In such a situation, a diversion ditch is necessary when a large upstream area drains directly into the tailings pond.

Movable wheel-mounted pumps may be placed at the clear-water pool on the natural soil within the tailings area. As the water rises they can be moved upstream. They have the same advantages and disadvantages as the barge pump, but because they need long suction lines, they are not as efficient.

Siphons are not recommended for regular tailings dams because the water they use must be near the dam, which creates instability. They can be used for water-reservoir type tailings dams only.

What are common causes of tailings dams failures?

Tailings dams and ponds fail because of seismic shock and/or poor construction, design, or operation.

Discussion:

The typical tailings dam failure is the curved-arc failure, which results from saturated embankments. Failure occurs when the driving force is greater than the resisting force of the soil. While water does not reduce or change the shear angle, it can reduce the cohesion to zero and add weight to the driving force to increase the chance of failure.

Computer programs are available that can calculate the safety factor of an embankment.

When should a tailings area be reclaimed?

Tailings areas should be designed so that they can be reclaimed in stages. Tailings ponds that have not been designed for staged reclamation should be reclaimed either when they are full or when they are no longer needed for the mining operation.

Additional Information:

For more information on tailings areas, refer to "Design Guide for Metal and Non-Metal Tailings Disposal," by Richard A. Busch and Roy Soderberg. U. S. Bureau of Mines Information Circular 8755. 1977.

SUBSIDENCE IN UNDERGROUND MINING

What factors potentially influence subsidence?

Subsidence is a local lowering of surface land caused by the collapse of rock and soil into an underground void. Subsidence, which can result in stability failures such as landslides and mine-roof cave-ins, is influenced by geologic structure, faults, joints, ground water, and the lithology of the overburden. The thickness, area, and number of ore seams mined determine the size of the void and the extent of subsidence.

Discussion:

Even if subsidence is contained in a relatively small area underground, it may have widespread impacts on surface lands. Thus, the unknowns involved in predicting subsidence, particularly where mining methods employed leave potentially unstable mine voids, make reclamation and land-use planning difficult for many years. Even when relatively safe land-use options can be determined, controlling surface land use is still a problem, because of conflicts between the rights of minerals and surface owners, as well as the increasing demand for use of surface land.

What is the geotechnical engineer's role regarding subsidence?

In order to evaluate potential subsidence, it is necessary to have a firm geotechnical base about the strength of the ore, the mine roof, the mine floor, the present condition of the materials, and what can happen should the materials become weathered or saturated over long periods of time.

Discussion:

Subsidence can be controlled to some degree by the method of mining. There is less potential for subsidence, for example, when the room-and-pillar method of mining is used. This method entails leaving 40-60 percent of the mineral in the ground to support the roof. Still, stability of these pillars is unpredictable, and it is not known whether they will deteriorate with time. This method may not be compatible with energy conservation policies. Also, leaving coal in the mine to protect the surface can produce fires, because subbituminous coal is conducive to spontaneous combustion.

Chapter 7
AIR QUALITY

Chapter Organizer: James Butler

Major Contributor: James Butler

As a result of the Clean Air Act of 1963 and its subsequent amendments, particularly the 1977 amendments, the problem of air pollution produced by mining has assumed a greater significance than it had in the past. Under the 1977 amendments, Federal Land Managers (FLM's), defined by law as the Secretary of Agriculture and the Secretary of Interior, are charged with insuring that users on Federal lands comply with National Ambient Air Quality Standards (NAAQS). In the case of National Forest System lands, the Secretary of Agriculture has delegated this authority to the Chief, who in turn has passed it to the Regional Forester. At the forest level, the Regional Forester will rely on input from the land manager, and in some cases the engineering staff, to make sure that mining operators have provisions in the operating plan to meet these standards.

POLLUTION IN MINING

What types of air pollutants does mining produce?

There are two major types of mining pollutants—particulates and gases. Particulates occur when the fine particles produced by mining disturbance are picked up and carried by the wind. The use of heavy equipment for extracting and transporting minerals results in high gaseous pollutant levels of carbon monoxide, nitrogen oxides, ozone, and sulfur dioxide, as well as some particulates. Of the two types of pollutants, particulates are by far the most important, because they are the most difficult to control.

Discussion:

Air pollution caused by mining may come from either point (stationary) or nonpoint (fugitive) sources. Until recently, point sources have been considered to be smelter stacks, electric-generating plants burning fossil fuels, or other easily identifiable industrial operations. Now the trend is toward a broader definition, and what were once thought of as nonpoint sources are now considered point sources. Some examples are drilling operations, crushing and screening equipment, conveyors, and transshipment points for minerals.

Nonpoint sources are generally extensive and difficult to control. Pollution from nonpoint sources can result from activities such as blasting and hauling minerals over roads, as well as dust from tipples, mineral stockpiles, tailings, and waste dumps prior to mulching and/or revegetation.

It is important for the Forest Service engineer to determine whether air pollution is being discharged from a point or a nonpoint source. The Clean Air Act and State air-quality laws require permits before allowing the release of more than 250 tons/yr of pollutants from stationary point sources, other than those specifically mentioned in Section 169 of the Clean Air Act amendments of 1977.

What do National Ambient Air Quality Standards (NAAQS) consist of?

NAAQS are divided into primary standards, which protect the public safety and health, and do not consider the economics of attainment; and secondary standards, which protect the public welfare, vegetation, and wildlife, and do consider the economics of control.

Discussion:

To meet National Ambient Air Quality Standards, limitations are placed on six emissions: total suspended particulates, sulfur dioxide, ozone, nitrogen dioxide, lead, and carbon monoxide (table 3). Some States have also set emission standards for other particulates and gases.

What are air-quality areas?

The Clean Air Act established three categories of clean-air standards: Class I (The most restrictive), Class II (less restrictive), and Class III (the least restrictive). Every area in the country falls into one of these categories. There are also nonattainment areas, where NAAQS are exceeded for one or more emissions. Nonattainment areas can be declared in any one of the three classes.

Discussion:

The Act designates these areas as Class I: International parks, and national wilderness areas and national parks exceeding 5,000 acres. National parks larger than 6,000 acres that existed on the date the 1977 Clean Air Act amendments were passed may not be redesignated to a lower category.

The Act designated all other areas in the country as Class II or III. States may redesignate Class II areas as either Class I or Class III, but most States have few, if any, Class III areas. Instead, they have chosen to use the nonattainment status for metropolitan and industrial areas with high concentrations of pollution. All nonattainment areas must achieve NAAQS within certain time frames. These schedules have to be approved by the Environmental Protection Agency (EPA), which is the Act's regulatory agency.

Units of Federal land larger than 10,000 acres that fall into the following categories are designated as Class II: all national forests and most Bureau of Land Management land. Some wilderness areas, because of prior land use, are also designated as Class II. All these areas can be upgraded to Class I; however, National Monuments, primitive areas, preserves, National Recreation Areas, wildlife areas, lakeshores, and seashores cannot be reduced to Class III.

The Forest Supervisor, with approval of State and local governments, can recommend that certain areas be redesignated as either Class I or Class III.

What is the Federal Land Manager's responsibility under the clean-air amendments?

The Federal Land Manager (Secretary of Agriculture) is charged with direct responsibility for and must take affirmative action to protect air-quality related values (including visibility) of Class I Air Quality Areas. This responsibility also applies to Class II areas.

Table 3. — *Example of primary and secondary standards for sulfur dioxide and particulate matter*

Pollutant	Primary standard	Secondary standard	PSD increments[1] maximum allowable increase micrograms/m^3				Class I variances micrograms/m^3 165(d)(2)(C)(iv)	165(d)(2)(D)(iii)	
				Class I	Class II	Class III		low terrain	high[2] terrain
Sulfur dioxide	80 micrograms/m^3 - (0.03 parts/M) annual arithmetic mean	1,300 micrograms/m^3 - (0.5 parts/M) maximum 3 h concentration not to be exceeded more than once/yr	annual arithmetic mean	2	20	40	20	---	---
	365 micrograms/m^3 - (0.14 parts/M) maximum 24 h concentration not to be exceeded more than once/yr		24 h maximum	5	91	182	91	36	62
			3 h maximum	25	512	700	325	130	221
Particulate matter	75 micrograms/m^3 - annual geometric mean	60 micrograms/m^3 - annual geometric mean	annual geometric mean	3	19	37	19	---	---
	260 micrograms/m^3 - maximum 24 h concentration not to be exceeded more than once/yr	150 micrograms/m^3 - maximum 24 h concentration not to be exceeded more than once/yr	24 h maximum	10	37	75	37	---	---

[1] Prevention of Significant Deterioration (PSD) Increments.

[2] High terrain is any area with an elevation of 900 ft or more above the base of the stack of the facility.

Discussion:

In reality, the Forest Service land manager is responsible for protecting air quality on Forest Service administered lands. When the forest engineering staff is assigned air-quality responsibilities, it will supply information to the land manager. Thus, when an operating plan is submitted, the engineering staff will review it to make sure that air-quality provisions have been included. If the plan does not appear to comply with air-quality standards, the staff should either request further data, or else recommend modification of the operating plan.

THE STATES' ROLE IN AIR QUALITY

Do the States have any responsibility for protecting air quality?

Each State is required by the Clean Air Act to pass air-quality laws equal to or more stringent than the Federal law, or else be faced with Federal regulation within the State by the EPA.

Discussion:

All States have now passed their own clean air laws and are proceeding through the next required step, the regulation phase, which involves preparation and approval of the State Implementation Plan (SIP). A SIP is the document that sets standards and guides States in managing their air resources. An engineer should be familiar with his State's SIP—it defines specific local air-quality regulations.

What information can be found in a SIP?

Each SIP contains plans for implementing, maintaining, and enforcing primary and secondary NAAQS as required by Federal law. Each State's SIP also notes its own particular regulations for listed air pollutants.

Discussion:

States have established State Air Quality Control Regions within Federal Air Quality Control Regions. Each State Air Quality Control Region designated in the SIP sets forth certain emission limitations and other measures designed to prevent significant deterioration of air quality. States have then divided their Air Quality Control Regions into Class I, II, III, or nonattainment areas. While setting emission limitations for each class of air quality, States have established background baseline concentrations for the six NAAQS pollutants. Some States have also set emission standards for other particulates and gases. The States are bound by Federal regulations when setting up variances in emission standards. Presently, some variance is allowed only for sulfur dioxide and ozone.

DETERMINING AIR QUALITY

How does the engineer participate in determining the impact a mining operation will have on air quality?

The engineer will review the Environmental Assessment or Environmental Impact Statement for a proposed mining activity. Even when only a limited potential for gas or particulate emission exists, air-quality provisions must still fulfill National Environmental Policy Act requirements.

Discussion:

Few situations will require a State or Federal air-quality permits for premining activities. Care must be taken, however, to assure that any Class I areas near a single exploratory oil and gas or geothermal well are considered.

If mineral development takes place, the mining company will have to apply to the EPA or to the State if more than 100 tons/yr of emissions will occur from either a point or a nonpoint source, or if the emissions will exceed the NAAQS for the Air Quality Area. (The figure of 250 tons/yr of emissions mentioned previously is a standard for certain specified point source emissions. See Section 169 of the Clean Air Act amendments of 1977 for the specific list. The figure of 100 tons/yr is for those sources, point and nonpoint, that are not named specifically in the law.)

Should air quality appear to be a limiting factor, companies must gather as much data as possible, and if this information is still inadequate, must then set up monitoring stations to obtain further baseline air-quality information.

What happens if emissions cannot be held to State or Federal standards?

In this case, the company has three options: it can request variances in the emission

standards; the area may be redesignated from Class II to Class III, with the approval of the Forest Supervisor and local and State Governments; or the mining operator can acquire an existing company that already has an emission permit. If none of these steps is taken, the mining permit may be denied by the State or the EPA.

Discussion:

Regardless of the final outcome of the development, careful monitoring of baseline air quality is critical. The engineer should review the company's operating plan carefully, considering it in light of possible future expansion, reclamation and abandonment phases, and best available technology for emission control.

Additional Information:

For further information refer to:

"Amendments to Clean Air Act of 1963, Public Law 88-206," U. S. Govt. Printing Off., Serial No. 95-11. Nov. 1977.

"Clean Air Act of 1963, Public Law 88-206," U. S. Govt. Printing Off., 1963.

"Engineering and Design Manual—Coal Refuse Disposal Facilities," U. S. Dep. Inter., Mining Enforcement and Safety Admin.

"Environmental Impact of Mining," by C. G. Down and J. Stocks. Halsted Press, Division of John Wiley and Sons, New York. 1977.

"The Clean Air Act—An Analytical Discussion," by Neal Paulson and others. USDA For. Serv., Washington, D. C. Jan. 1978.

Chapter 8
RECLAMATION EQUIPMENT

Chapter Organizer: Donald Calhoun

Major Contributor: Donald Calhoun

Mitigating environmental damage caused by mining must always be a prime consideration when reviewing a company's operating plan. Although the Forest Service engineer will not be directly involved in the reclamation process, familiarity with the equipment available for mined-land reclamation will help with engineering decisions that must be made during the review procedure.

Several steps are involved in mined-land reclamation, including soils/spoils shaping, fertilizing, mulching, and planting. Many types of reclamation equipment are available to help accomplish these tasks. This chapter provides an overview of such equipment; the machines described are just a few of the ones that have been used successfully in mined-land reclamation. For more detailed information about reclamation equipment, refer to the notes at the end of the chapter. Selection of equipment will depend on its availability and capability, and the characteristics of the site and treatment it requires.

CURRENTLY AVAILABLE EQUIPMENT

What special equipment is available for shaping land prior to reclamation?

Some machines commonly used to shape land for reclamation are the V-Plow, the Big Dude, and the Grader Bar.

Discussion:

These three machines, designed and constructed by the Bureau of Mines in cooperation with the Pittsburg and Midway Mining Company, level or reshape large areas of spoil ridges that remain after surface mining. The first machine used in the process, the V-Plow, is a V-shaped dozer blade on a large dozer, with a second dozer that pulls a heavy cable attached to the point of the V-Plow. The V-Plow can knock the tops off spoil ridges and make a fairly level bench, 30-40 ft wide.

The Big Dude is the next machine used in this process. The Big Dude is a 40-ft-wide dozer blade, which is pushed by one D-9 and pulled by another. This machine can move very large amounts of material—an average of 6,000 yd^3/h—and it can level or reshape large areas of spoils.

The final machine used in this process is the Grader Bar, which is a normal type of dozer blade with low-height extensions added to each side, up to a total width of 30 ft. The Grader Bar does the final smoothing. After this step is complete, the area is ready for planting.

What machines are primarily used for fertilizing?

The Estes spreader is a machine often used in fertilization, although conventional manure spreaders may also be used.

Discussion:

The Estes spreader is essentially a large hopper mounted on a truck. It has an auger in the bottom of the hopper that carries material to the rear of the machine, where it is picked up by a fan and blown out on the land surface. It can be used to spread fertilizer and lime, as well as certain types of mulches such as wood chips.

What special equipment is used for seeding and mulching land for reclamation?

Many types of equipment are available for seeding and mulching, including: the Hodder gouger and the Bozeman Basin blade, the hydroseeder, the Rangeland drill, the steep-slope scarifier-seeder, heavy duty disks, manure spreaders, and the rotovator. The Estes spreader, used for fertilizing, can also be used to spread certain types of mulch.

Discussion:

The Hodder gouger was designed and built to create small depressions in the soil to improve conditions for growing vegetation on reclaimed lands. The latest model is pulled behind a wheel tractor and, through a hydraulic cycling system, creates depressions in the soil surface that are about 2 ft long, 1 ft wide, and 8 in. deep. It also contains a seed box with tubes, which distributes a seed mixture into the depressions. This process creates better moisture conditions for vegetation and minimizes the adverse effects of wind. The Hodder gouger is used on slopes of 10 percent or less (fig. 10). The Bozeman Basin blade was designed to accomplish similar tasks, but the basins are much larger—8 ft wide, 15 ft long, and 2 ft deep. It is attached to the rear of a dozer and is used on slopes of up to 45 percent (fig. 11).

The hydroseeder is indispensable for certain land and climate conditions. It simultaneously applies a seed mixture, fertilizer, mulch, and a small amount of water. It is especially useful on steep slopes where conventional machinery cannot operate.

The Rangeland drill is a single-disk, deep-furrow drill with a high clearance, which has the advantage of being able to plant to greater depths in low-precipitation areas. It is useful on clay loam soils that have been previously tilled.

The steep-slope scarifier-seeder prepares seedbeds and plants seeds on very steep slopes, primarily above and below road fills or cuts. The machine is attached to the end of a hydraulic crane with an extendable boom.

Heavy-duty disks can be used for several purposes. Recently they have been used at some mined-land reclamation sites to incorporate

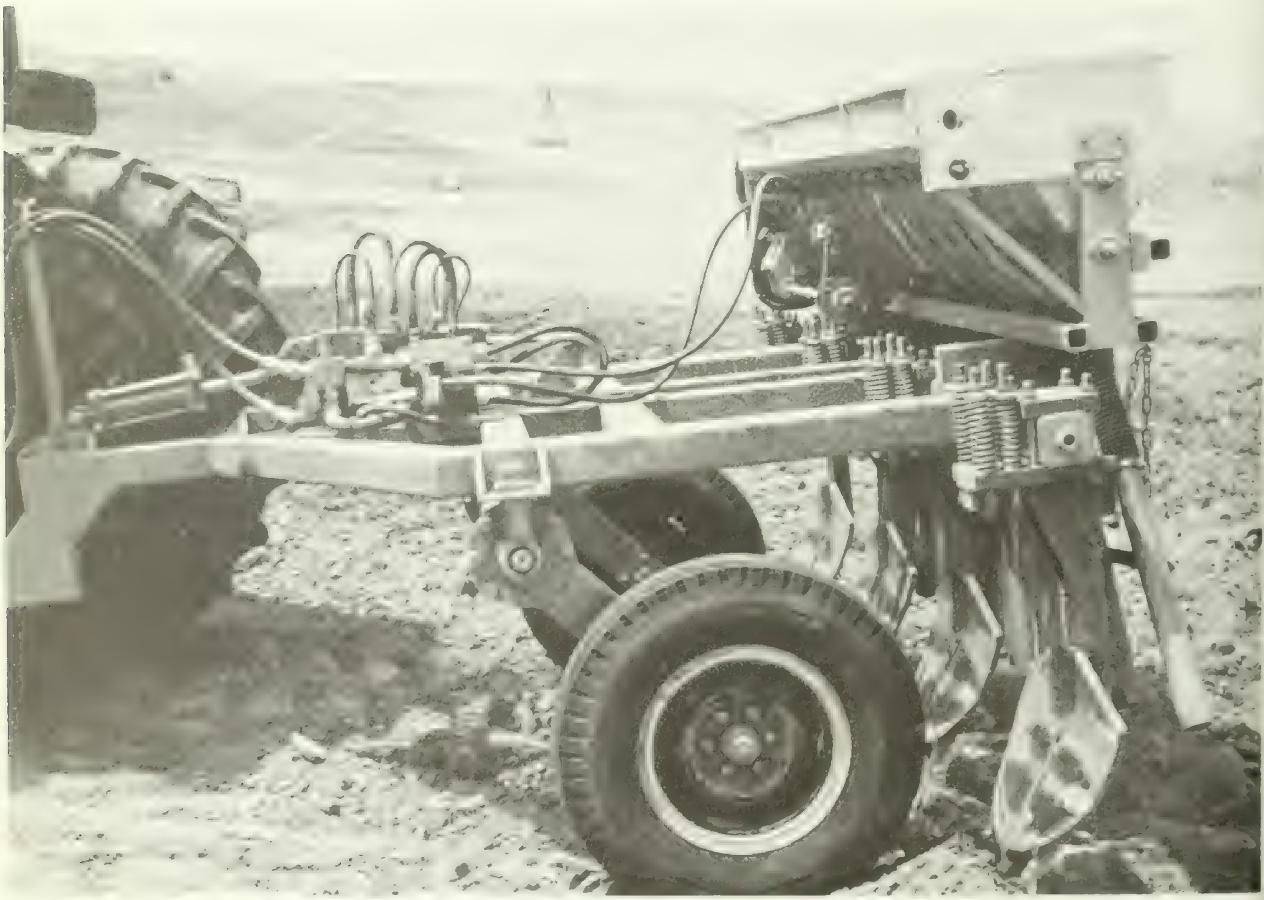

Figure 10. The Hodder gouger. (Donald Calhoun, U. S. Bureau of Land Management)

mulch or lime, and they can also be used to relieve compaction in the soil's surface layer.

Conventional manure spreaders have been modified so that they can become effective mulch spreaders. They can handle and distribute almost any type of mulch, including straw, hay, sludge, sawdust, and woodchips.

The rotovator is another machine that has been effective in incorporating mulch into the surface layer of the soil. It is useful in areas where rocks are neither too numerous nor too large.

What machines are used to plant on reclaimed lands?

The two machines mainly used to plant on reclaimed lands are the tree spade and the tree planter.

Discussion:

The tree spade is a tree-transplanting machine that was developed to establish clusters of trees and shrubs on mined-land reclamation sites. The tree spade can be mounted on a trailer, truck, or front-end loader. A special trailer has been developed for this machine that carries eight tree transplants at a time (fig. 12).

The tree planter, which has been used for many years in reforestation programs, has recently been used effectively to plant trees on reclamation sites.

Is there any reclamation equipment that needs to be improved?

Yes, improvements need to be made on machinery designed to collect native seeds.

Figure 11. The Bozeman Basin blade. (Donald Calhoun, U. S. Bureau of Land Management)

Discussion:

While some machines have been designed to collect native seeds, more work is needed in this area. Past efforts have included combine-type machines, truck-mounted vacuum-type machines, and backpack vacuum-type machines. It is felt that a more desirable native-seed collector would be a lightweight, vacuum-type machine that could be carried on bicycle wheels.

EQUIPMENT UNDER DEVELOPMENT

What are some future special-equipment needs for mined-land reclamation?

Some foreseeable equipment needs are for a bucket wheel excavator system with conveyor belts and stackers, a vertical mulcher, and a tubeling transplanter.

Discussion:

Bucket wheel excavators efficiently handle large volumes of overburden—currently 314,136 yd^3 of material per day. They have been used in the United States on a limited basis and in Europe extensively (fig. 13). This system would be feasible if a surface mine was quite large and expected to operate for 100 or more years. A conveyor-belt system would need to be used in conjunction with the bucket wheel excavators, and conveyor belts that are up to 10 ft wide are now being used in Europe. They are mobile, maintenance free, have variable speeds, have a life expectancy of 20 years, and they can move enormous amounts of material. The third component of the system consists of a stacker, which takes the material from the conveyor belt and places it in the mined-out pit. With proper manipulation, the material can be placed back in

Figure 12. The tree spade. (Donald Calhoun, U. S. Bureau of Land Management)

the pit in the same relative profile location from which it came, and in such a way that little reshaping is necessary to achieve a useful land surface.

The vertical mulcher has already been used in some agricultural areas of the United States; it may also become a feasible approach to reclaiming areas where moisture penetration is a serious problem, such as at some sites mined for bentonite. It uses a ripper-tooth device behind a large dozer, with a hopper above the ripper tooth. The mulch is spread through the depth of the vertical space.

A tubeling transplanter would plant containerized plants with developed root systems in a planting medium on a reclaimed site intact. Tubeling transplanters would be especially useful where conditions are severe, such as with tailings ponds, where there is low precipitation, or with vegetation that is difficult to establish.

Additional Information:

For more information on reclamation equipment, refer to "Handbook—Equipment for Reclaiming Strip Mined Land," by Darrell Brown. USDA For. Serv., Northern Region, Missoula, Mont. Feb. 1977.

Figure 13. A bucket wheel excavator. (Donald Calhoun, U. S. Bureau of Land Management)

APPENDIX A

GLOSSARY

Aquifer: A geologic formation or structure that transmits water. Aquifers are usually saturated sands, gravel, fractured rock, or cavernous rock.

Baseline data: Data gathered prior to mining for the purpose of outlining conditions existing on the undisturbed site. Reclamation success is measured against baseline data.

Clean Air Act of 1963 and subsequent amendments: This Act limits emissions through National Ambient Air Quality Standards (NAAQS). NAAQS consist of primary standards, which protect the public safety and health, and secondary standards, which protect public welfare, vegetation, and wildlife. The Act established three classes of air standards, Class I being the most restrictive, and each area in the country has been designated a class. When these standards cannot be met, an area may be classified as a nonattainment area.

Clean Air Act 1977 amendments: Under the 1977 amendments, Federal Land Managers (Secretary of Agriculture and Secretary of Interior) are responsible for making sure that users of Federal lands comply with NAAQS.

Core: The sample of rock obtained through the use of a hollow drilling bit, which cuts and retains a section of the rock penetrated.

Dump: Also called fill, backfill, spoils pile, waste-disposal area, or storage site. An area where overburden is piled during the mining process, either temporarily or permanently.

Environmental Assessment (EA) (Replaced the EAR): An analysis of all actions and their predictable short- and long-term environmental effects, which include physical, biological, economic, and social factors and their interactions. Also, a concise public document required by the regulations for implementing the procedural requirements of the National Environmental Policy Act of 1969 (NEPA).

Environmental Impact Statement (EIS): A document prepared by a Federal agency in which anticipated environmental effects of a planned course of action or development are evaluated, as prescribed by the National Environmental Policy Act of 1969 (NEPA).

Erosion: The group of physical and chemical processes whereby earth or rock material is worn away, loosened, or dissolved and removed from any part of the earth's surface. It includes the processes of weathering, solution, corrosion, and transportation.

Exploration: The search for economic deposits of minerals, ore, gas or oil, or coal, through the practices of geology, geochemistry, geophysics, drilling, shaft sinking, and mapping.

Feasibility study: Analysis of the rate of return that can be expected from the mine at a certain rate of production. Based on this study, the decision to develop the ore body may be made.

Forest plan: According to Forest Service regulations, each forest must have a forest plan, which outlines the most desired and alternative land uses for that site.

Geotechnical engineering: A branch of engineering that is essentially concerned with the design aspects of slope stability, settlement, earth pressures, bearing capacity, seepage control, and erosion.

Ground water: Water within the earth that is in the zone of saturation where all openings in soils and rocks are filled—the upper surface of which forms the water table; water that supplies wells and springs.

Impoundment: The accumulation of any form of water in a reservoir or other storage area.

Infiltration: The movement of water into the soil through pores or other openings.

Interdisciplinary team (ID team): A team composed of Forest Service personnel who collectively represent specialized areas of technical knowledge about natural-resource management applicable to the area being planned. The team will consider problems collectively, rather than separating them along disciplinary lines. This interaction will insure systematic, integrated considerations of physical, biological, economic, and social sciences and design arts.

Land-management plan: See forest plan.

Leaching: The removal of soluble constituents from a substance by the action of a percolating liquid.

Mine-waste disposal embankment: An earth and rock structure that encloses mining waste materials. Also see Dump.

Mineral beneficiation: The process of treating ore so that the resulting product is richer or more concentrated with minerals. It is primarily a milling and concentrating process.

Mining plan: See operating plan.

Monitoring: The careful observation and sampling of an activity to insure that the design objectives are being met.

Mulching: Placing or leaving nonliving material on or near the soil surface for the purpose of protecting the surface from erosion or protecting plants from heat, cold, or drought.

National Ambient Air Quality Standards (NAAQS): See the Clean Air Act of 1963 and subsequent amendments.

Native species: Plants that originated in the area in which they are found; i.e., they naturally occur in that area.

Nonattainment area: See the Clean Air Act of 1963 and subsequent amendments.

Nonpoint air pollution: Pollution caused by sources that are nonstationary. In mining, nonpoint air pollution results from such activities as blasting and hauling minerals over roads, as well as dust from tipples, mineral stockpiles, tailings, and waste dumps prior to mulching and/or revegetation.

Operating plan: Submitted by the mining operator, the operating plan outlines the steps the mining company will take to mine and rehabilitate the site. The operating plan is submitted prior to starting mining operations. For the purpose of this guide, the term operating plan is used synonymously with the term mining plan.

Overburden: Material overlying a deposit of useful materials, ores, or coal.

Performance bond: A bond of liability placed on a mining company. The bond specifies regulations for determining the acceptability of certain mining and reclamation activities.

Phreatic water line: The top of the free-water surface within the body of a dam or tailings embankment.

Piezometer: A pressure measuring instrument used either to locate the elevation and slope of the phreatic surface or to measure the hydraulic head of confined water.

Point air pollution: Pollution that results from stationary sources. In terms of mining, some examples of point sources are drilling operations, crushing and screening equipment, conveyors, and transshipment points for minerals.

Preliminary site reconnaissance: A site-specific survey that takes place before decisions are made that affect land allocation for a particular activity. It includes investigation of such items as terrain, slope, drainage crossings, hydrology, and vegetation.

Reclamation: Returning disturbed land to a form and productivity that will be ecologically balanced and in conformity with a predetermined land-management plan.

Rehabilitation: See reclamation.

Safety factor: A safety factor is a ratio of resisting forces to driving forces. By determining a structure's safety factor, a numerical index of stability is obtained.

Sediment: Solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level.

Sediment basin: A pond, depression, or other device used to trap and hold sediment.

Slumping: A sudden sliding or sinking of the slopes of a mine dump, generally caused by excess water in the dump or foundation.

Soil: The loose surface material of the earth, usually consisting of disintegrated rock and a mixture of organic matter and soluble salts.

Spoils: Any dirt or rock that has been removed from its original location by mining operations.

Spoils dump: See dump.

State Implementation Plan (SIP): A document that sets standards and guides States in managing their air resources. It defines specifically local air-quality regulations, and contains plans for implementing, maintaining, and enforcing primary and secondary National Ambient Air Quality Standards as required by Federal law.

Stockpiling: Storage of material for later use.

Stripping ratio: The number of units of unpayable material that must be mined to expose one unit of ore.

Subsidence: A local lowering of surface land caused by the collapse of rock and soil into an underground void; it can result in stability failures such as landslides and mine-roof caveins.

Surface runoff: The moisture that is not absorbed by the soil.

Tailings: The waste material that remains after the valuable minerals have been removed from raw materials by milling.

Tailings sites: Areas, including embankments and ponds, retaining the fine waste from milling operations.

Talus slope: A natural slope formed by the accumulation of rocks and rock debris at the base of a steep rock face.

Watershed: The total area above a given point on a stream that contributes water to the flow at that point.

Water table: The upper surface of the ground water or that depth below which the soil is saturated with water.

APPENDIX B

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USDA Forest Service.

1979. User guide to engineering. USDA For. Serv. Gen. Tech. Rep. INT-70, 58 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Summarizes and discusses key questions and rules the engineer should consider when working in mining area reclamation. Topics include preliminary site reconnaissance; computer-aided planning tools; transportation systems; minerals exploration and development facilities; geotechnical engineering and mining practices; mass stability; air quality; and reclamation equipment.

KEYWORDS: engineering, mining, operating plan, transportation facilities, geotechnical practices, air quality, mass stability.

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THE SEAM PROGRAM

The Surface Environment and Mining Program, known as SEAM, was established by the Forest Service to research, develop, and apply new technology to help maintain a quality environment while helping meet the Nation's mineral requirements. SEAM is a partnership of researchers, land managers, mining industries, universities, and political jurisdictions at all levels.

Although the SEAM Program was assigned to the Intermountain Station, some of its research projects were administered by the Rocky Mountain and Pacific Southwest Research Stations.

MINERAL USER GUIDES

Other User Guides for specialists involved in minerals activities are:

- User Guide to Vegetation, Gen. Tech. Rep., INT-64
- User Guide to Soils, Gen. Tech. Rep., INT-68
- User Guide to Sociology and Economics, Gen. Tech. Rep., INT-73
- User Guide to Hydrology, Gen. Tech. Rep., INT-74
- User Guide for Wildlife (planned)
- User Guide for Visual Management (to be published as part of the National Forest Landscape Management Series)

To obtain copies of these guides, write: Intermountain Forest and Range Experiment Station, USDA Forest Service, 507 25th St., Ogden, UT 84401.

SURFACE ENVIRONMENT & MINING
SEAM
USDA FOREST SERVICE PROGRAM

PROCEDURES RECOMMENDED FOR OVERBURDEN AND HYDROLOGIC STUDIES OF SURFACE MINES

Thunder Basin Project

U.S.D.A. FOREST SERVICE
GENERAL TECHNICAL REPORT INT- 71
INTERMOUNTAIN FOREST AND RANGE
EXPERIMENT STATION
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

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PROCEDURES RECOMMENDED FOR OVERBURDEN AND HYDROLOGIC STUDIES OF SURFACE MINES

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RESEARCH SUMMARY

This report outlines the kind of information required to evaluate the soils, overburden, and hydrology so that appropriate land management decisions can be made regarding the selection of mineral lease sites, the development of lease stipulations, and the formulation of mining and reclamation plans. In addition, cost effective procedures are presented for data acquisition and analysis associated with soils, overburden, and hydrologic studies.

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RATIONALE AND PROBLEM IDENTIFICATION

Thorough analysis and planning for reclamation of lands disturbed by surface mining and for the control and mitigation of potential water quality degradation can preserve the long-term productivity of the land and the integrity of the water resources without undue hindrance to the development of mineral resources. This goal can be achieved through evaluation of the characteristics and interrelationships of soils, overburden, surface water, and ground water; thereby permitting rational assessment of alternatives for exploration, mining, and reclamation activities.

This project was a part of the 17-agency Federal Energy/Environment Research and Development Program. It was partially funded by the Surface Environment and Mining Program (SEAM) of the USDA Forest Service and by the U.S. Environmental Protection Agency to develop recommendations and criteria for the study of soils, overburden, and hydrology at surface mining sites. Two basic goals were established for the project:

1. Determine the kinds of information required to evaluate the soils, overburden, and hydrology so that appropriate land management decisions can be made relative to the selection of lease sites, development of lease stipulations, and formulation of mining and reclamation plans.

2. Recommend cost effective procedures for data acquisition and analysis associated with soils, overburden, and hydrologic studies.

The objectives are achieved by defining soils, overburden, and hydrologic information requirements and by evaluating and prioritizing alternative approaches to sampling and analysis where possible. The purpose is to assist in making leasing, mining, and reclamation decisions that give due consideration to surface stability, soil and overburden fertility, occurrence and distribution of toxic materials, surface and ground water quality and quantity, and future land and water uses. The information requirements and procedures for analysis are derived with the recognition that the chemical, mineralogical, and textural characteristics of soils and overburden affect fertility, stability, weathering (weatherability), erosion, water quality, runoff, and recharge. Also, the data needs that were developed reflect the requirement that the relationships among topography, geology, climate, vegetation, surface water, ground water, water quality, and water use must be adequately understood.

This handbook has been prepared as a result of the SEAM study. No attempt was made to identify all available technology and information available for the study of soils, overburden, and hydrology; but rather to recommend proven methods and procedures that are known to give good results. References are cited so that the reader can obtain more detailed information when desired.

The Final Report of the SEAM Thunder Basin Project summarizes an evaluation of site-specific data on a study site in Campbell County, Wyoming. This report includes an evaluation of data on geology, mineralogy, texture and geochemistry of overburden, discussion of plant growth studies, and surface and ground water hydrology.

DATA REQUIREMENTS AND COLLECTION PROCEDURES

Sources of Existing Data

GENERAL SOURCES OF DATA

From a mining company standpoint, the information required for a literature review must include knowledge of the various disciplines which influence property evaluation. For an initial literature review the available data in the following areas should be examined: (a) geology, (b) hydrology, (c) soil science, (d) environmental science, (e) legal, and (f) mining. Such data can be extracted from a number of sources including government agencies, technical journals and books, university publications, and private sources. Sources of information in the areas, excluding legal and mining, will be covered in detail below.

Appendix I is a list of sources for geological, hydrological, soils, and reclamation data. This list is modified extensively from Peters (1978). Most of the sources can be found in university libraries and all of the geological references are available in the United States Geological Survey (USGS) Library in Denver, Colorado. Perhaps the best general source for geological information is the book by Wood (1973). The best overall source of information on the collection of subsurface data and the analysis of subsurface samples is LeRoy and others (1977). State geological surveys and/or bureaus of mines should always be consulted at an early stage for geological information on a particular local area. A list of state geological surveys in the Rocky Mountain Region is included as appendix II.

UNPUBLISHED DATA SOURCES

Most Federal and State bureaus of mi and geological surveys, State regulatory agenci industry clearinghouses, regional research orga zations, and private consulting firms have p liminary reports, project files, and raw numeri data on file. Open file reports of the U.S. G logical Survey and the U.S. Department of Ene are available for public inspection. Copies these reports can often be obtained for the c of photocopying.

Detailed unpublished material on conser tion and management practices are available local Soil Conservation Service offices. Also av able are lists of important and prime farml that may occur in each county or planning u

The Forest Service and Bureau of La Management have management plans which c tain information on existing resources wit certain management units of public lands. T information is available for public inspection.

COMPUTERIZED DATA BANKS

As the wealth of knowledge in vari scientific disciplines becomes greater, there i ever-increasing need for computerized data ba to handle storage and retrieval of this infor tion. Some of the more important geolog data banks are given below:

RASS, Rock Analysis Storage Syst Used within the U.S. Geological vey. Files not available to the pu

but some data are released on magnetic tape. Washington, D.C.

SSIE, Smithsonian Science Information Exchange. Information on research in progress. Washington, Smithsonian Institution.

CRIB, Computerized Resources Information Bank. Used within the U.S. Geological Survey, Washington, D.C.

DATRIX, Direct Access to Reference Information, Theses and Dissertations. University of Michigan, Ann Arbor, Michigan.

Geo-Archives. London, Geosystems (Lea Associates Ltd.).

GEODAT, numerical results produced by laboratories in the Geological Survey of Canada. Chemical, spectrographic, and age data. Available to users in the private sector. Geological Survey of Canada, Ottawa.

Geo Ref, a geoscience-oriented service provided by the American Geological Institute and the Geological Society of America; files date from 1966.

GRASP, Geological Retrieval and Synopsis Program. Used within the U.S. Geological Survey, Washington, D.C.

SOURCES OF MAPS AND AERIAL PHOTOGRAPHS

Topographic Maps

About 90 percent of the United States is covered by 1:62,500 (15-minute quadrangle) to 1:24,000 (7-½-minute quadrangle) topographic mapping. Indexes to topographic mapping in each state are published quarterly by the U.S. Geological Survey. These and the topographic maps are obtainable by mail from the U.S. Geological Survey offices in Denver, Colorado, for the Western States. Copies of U.S. Geological Survey topographic maps and advance prints of preliminary quadrangle maps are also available (although not by mail) from district U.S. Geological Survey offices and from State geological surveys and bureaus of mines at the addresses shown by Wood (1973), and Ward and Wheeler (1972).

Geology, Geophysics, and Soil Maps

Government geologic mapping in the United States covers most of the country at a scale of 1:500,000 (state maps), about 40 percent of the country at a scale 1:250,000, and about 25 percent of the country at 1:62,500 to 1:24,000. Unlike topographic mapping, some of the geologic mapping has been done by the State geologic surveys. In addition, some areas have been mapped for universities by candidates for advanced degrees. Even though the maps are scattered through Federal, State, and scientific association publications, most states have an updated index to geologic mapping compiled by the U.S. Geological Survey or by the State bureau of mines. Special map series produced by the USGS include:

Coal Investigation Maps.

Geologic Quadrangle Maps. This series is a continuation of the Geologic Folios published between 1894 and 1946.

Geophysical Investigations Maps. This series includes aeromagnetic and radiographic maps at 1:62,500 and 1:24,000 scale.

Hydrologic Investigations Maps.

Mineral Investigations Field Studies Maps. This series includes preliminary tectonic, metallogenic, mineral deposits, and geological maps.

Mineral Investigations Resource Maps. These are mineral deposit maps.

Miscellaneous Geological Investigation Maps. This series includes photogeologic maps, and paleotectonic maps.

Oil and Gas Investigations Maps.

Detailed soil inventories conducted by the Soil Conservation Service, Bureau of Land Management, and the Forest Service are available for certain areas throughout the Western United States. Information is available at these agencies' State or regional offices. State general soil maps with scales of about 1:500,000 and county general soil maps and prime farmland maps with scales of 1:100,000 to 1:250,000 are, or will be available from the Soil Conservation Service in each Western State.

Aerial Photographs and Spacecraft Imagery

Aerial photography coverage in the United States is shown on the U.S. Geological Survey quarterly indexes to topographic mapping for each state. Smaller scale indices to aerial photography coverage of the entire country are also published from time to time. Indices and advice on coverage by government agencies for specific areas can be obtained from the National Cartographic Information Center, U.S. Geological Survey, National Center (STOP 507), Reston, Virginia 22092.

The U.S. Geological Survey EROS Data Center, Sioux Falls, South Dakota 57198, is the source for copies of geological survey aerial photographs, NASA photography and imagery, LANDSAT Imagery, and Skylab photography and imagery. (The abbreviations here are: EROS = Earth Resources Observation Systems; NASA = National Aeronautics and Space Administration; and LANDSAT = the former ERTS, Earth Resources Technology Satellite.) Satellite imagery is available on magnetic tape and in photographic form. Standard catalogs and film strips as well as transparencies, paper prints, enlargements, and state image maps are available. A geographic search and inquiry system provides free information on specific photographic coverage. EROS application assistance facilities and data reference files are located at more than a dozen offices throughout the United States.

LANDSAT mapping programs have been completed for several states. Included among these is the LANDSAT mapping program for North Dakota completed by the North Dakota Regional Environmental Assessment Program (NDREAP).

Field Surveys

GEOLOGIC OVERBURDEN

The primary objectives of field reconnaissance are to verify the existing data and to seek out new field data that might have been overlooked by previous workers.

The verification of existing data is accomplished by aerial photographic interpretation and by field examination of outcrops, roadcuts, active and/or abandoned mine workings, and stored cores and geophysical logs. Access to mines and private property may be restricted. Considerable advanced planning is usually required to obtain access to these properties. No new drilling or test pit work is undertaken during these surveys. The final products of a field survey will probably constitute detailed geologic and topographic maps of the proposed mine area at an appropriate scale. Other information plotted on surface maps will include borehole and pit locations, access routes, and surface drainage.

SOIL

Definition of the Soil

Basic to determining the kind and intensi[illegible] of inventories necessary to provide informati[illegible] needed by planners and resource managers [illegible]volved in reclamation planning, is a definition [illegible] the resource being inventoried. "Soil," as co[illegible]ceived by some, consists of the unconsolidat[illegible] materials found near the earth's surface. Th[illegible] schematic soil profile shown in fig. 1 reflect[illegible] the concept of soil as it is considered in this re[illegible]port. This diagram illustrates that chemical, bi[illegible]logical, and physical processes give rise to s[illegible] layers that are significantly different in terms [illegible] their chemical, physical, and biological pro[illegible]erties. These differences in basic properties [illegible] turn affect other characteristics such as pla[illegible] nutrient status, available water capacity, ero[illegible]bility, infiltration, and permeability propert[illegible] which are very important in assessing the opp[illegible]tunities and/or constraints that soils offer in [illegible]veloping management alternatives for reclaimin[illegible] a tract of land which will be disturbed by minin[illegible] activity.

Using this concept of soils, this approa[illegible] ensures greater reliability for separating natu[illegible] soil bodies into groups which are different, a[illegible] prevents mixing or grouping of unlike soils a[illegible] allows for maximum utilization of existing s[illegible] data. Separation into genetic horizons [illegible] extremely critical in sampling for laborato[illegible] analyses.

Purpose of Soil Inventory

The purpose of a soil inventory is to provide answers to the following questions:

1. What land capabilities exist at the present time? Prime, important, and unique farmlands need to be identified along with the agricultural productivity potential of the area.

2. What opportunities and/or constraints do soils offer, based on availability of materials, for developing management alternatives for reclaiming a tract of land to be disturbed by surface mining?

In order to answer these questions, it follows that the soil inventory must identify:

1. The different kinds of soils that occur, based on physical, chemical, and depth characteristics as well as other features which affect use such as slope, stoniness, etc., and

2. The area extent and distribution of soils is exhibited on a soil map.

The discussion that follows provides information that can be used for determining the kind and intensity of soil inventory that would provide land managers, planners, and mine operators with the kind of soil information needed in developing a reclamation plan.

Design of Soil Inventory

The design of a soil inventory program should consider the following factors:

1. Map scale and survey intensity,
2. Soil description procedures,
3. Soil mapping unit description procedures,
4. Soil classification and correlation,
5. Sampling.

Map Scale and Intensity

Information shown in table 1 summarizes the relationships between soil inventory intensity and level of detail at which "map unit delineations" are recognized and soils are classified. The information shown is a general guideline used by the Soil Conservation Service in planning for soil inventory intensity. Information shown in table 2 shows similar guidelines as developed and used by the U.S. Bureau of Reclamation for making irrigation suitability inventories. Perhaps the most important factors as shown in the two tables are the "size of area" that is delineated on a map as a function of scale and the level of abstraction at which soils and/or land information is defined. Except for using the equivalent of an Order 3 (table 1) type inventory for general planning, it appears that an inventory equivalent to Order 1 or 2 is necessary if all soil data needed in developing mined land reclamation planning is to be identified. The planner or land manager must decide on the intensity of the inventory needed based on the desired level of planning, i.e., the level of detail needed for a "prospecting phase" vs "reclamation phase."

Soil Description Procedures

Purpose. Soil profile descriptions are useful for identifying changes with depth in terms of soil texture, structure, presence, or absence of calcium carbonate, color, and thickness of individual soil layers or horizons. These characteristics are important for determining sampling needs as well as for planning a "topsoil stockpiling program." The form shown in table 3 could be used in describing soil profiles. The form allows for collecting site related information in addition to soil characteristics. The purpose of this is to allow for coordination of soil data with other resource data collected. This maximizes the credibility of interpretations that are made from the data. Procedures for describing soil profiles can be found in "Soil Taxonomy" (Soil Survey Staff 1975) and "Soil Survey Manual" (Soil Survey Staff 1951).

Using the above approach provides a basis for identifying the different kinds of soils found on a tract of land, aids in separating soil horizons for the purpose of stockpiling for future reclamation and sampling for laboratory analyses and provides basic data needed for classifying the soils.

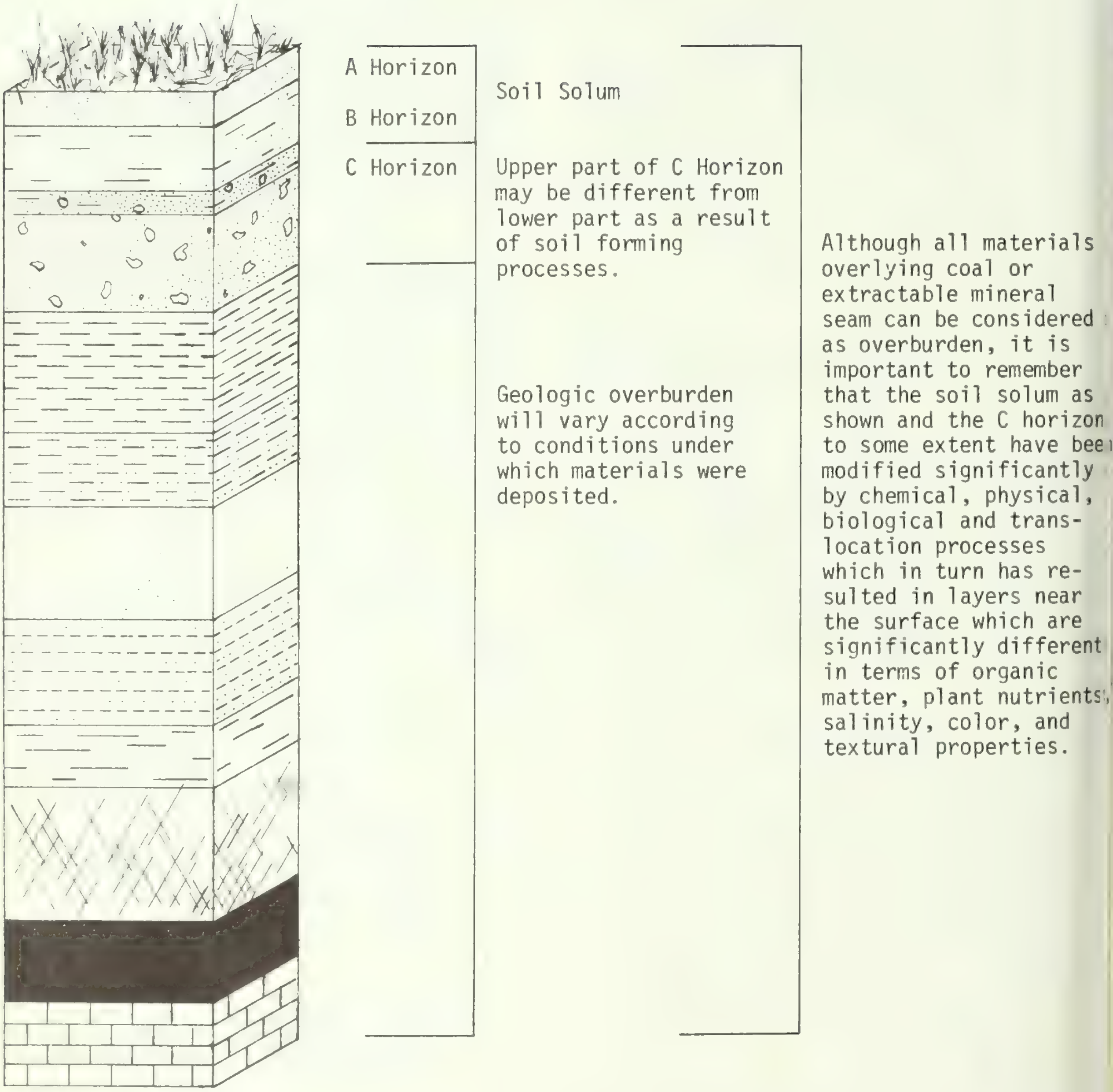


Figure 1. Schematic illustration of the relationship between soil and geologic overburden.

Table 1. — Relationships of soil inventory intensity and level of intensity at which map unit delineations are recognized and soils are classified

	Order 1	Order 2	Order 3	Order 4	Order 5
onomic sification	series	series	families and series	families and subgroups	subgroups, great groups, suborders, and orders
p unit	phases of soil series	phases of soil series	phases of soil series and soil families	associations with some consociations	associations
scale ded	1:12,000 and larger	1:12,000 to 1:31,680	1:24,000 to 1:250,000	1:100,000 to 1:300,000	1:250,000 to 1:1,000,000
llest mapped	less than 1.5 acres	1.5-10 acres	6-640 acres	100-1,000 acres	640-10,000 acres
ent dissimilar usions	less than 10 percent	less than 20 percent	less than 30 percent	not set in advance	not set in advance
pted uses	experimental plots and individual home sites ... the nearest survey intensity to being site specific	planning of moderately intensively used management units, based on predictions of the suitabilities and soils response to management	planning for extensive uses of land such as rangeland, watershed management, woodland, and extensive kinds of cropland...county, multicounty, or watershed planning	regional planning within multicounty or multistate areas or larger watersheds ... used to locate areas having potential for 2nd order survey and for site management planning	used for broadest kinds of planning for states or nations ... accurate identification of most important soils and reasonable estimates of their extent
e ods	Identification of soils of each delineation by direct examination of all boundaries throughout their lengths. Sampling plan of grid applied at random, in addition to soil examinations at places dictated by surface features that may mark soil differences. Laboratory determinations on samples collected at selected places to verify or augment field observations.	Identification of soils by transecting and transversing. Soil boundaries are plotted by observation and interpretation of remotely sensed data. Boundaries are verified at closely spaced intervals.	Soils in each delineation are identified by transecting and transversing and some observation. Boundaries are plotted by observation and interpretation by remotely sensed data and verified with some observations.	The soils of delineation representative of each map unit are identified and their patterns and composition determined by transecting. Subsequent delineations are mapped by transversing, by some observation, and by interpretation of remotely sensed data verified by occasional observations. Boundaries are plotted by air photo interpretations.	The soils, their patterns, and their composition for each map unit are identified through mapping selected areas (15 to 25 mi^2) with 1st or 2nd order surveys, or alternatively, by transecting. Subsequently, mapping is by widely spaced observations, or by interpretation of remotely sensed data with occasional verification by observation or transversing.

Table 2. — Some minimum map scale and observation requirements for land classification as used by the U.S. Bureau of Reclamation in determining irrigated land suitability

Specification	Reconnaissance map	Semi-detailed map	Detailed ma
Scale of base maps	1:24,000	1:12,000	1:4,800
Land classes recognized	1,2,3,6	1,2,3,6	1,2,3,4,5,6
Maximum distances between traverses (miles)	1.00	0.50	0.25
Accuracy (percent)	75	90	97
Field progress per day for one land classifier and crew (square miles)	3.00-5.00	1.00-3.00	0.25-1.00
Minimum soil borings or pits per square mile (5 ft deep)	1	4	16
Minimum number of deep substrata holes per township (10 ft deep or more)	1	2	4

Source: U.S. Bureau of Reclamation, 1953.

Detailed land classification (Bureau of Reclamation, 1953) is generally done at a map scale of 1:4,800 (400 feet to the inch) to provide adequate information as to the exten and character of the various lands in each 40-acre tract. A smaller scale, not less thar 1:12,000, may be used on fully developed areas or on highly uniform new land areas where no specific problems are associated with soils, topography, or drainage and none are anticipated. Base maps at scales of 1:24,000 are considered only for reconnaissance studies by the Bureau, and are used for preliminary elevations and for drainage basir studies (e.g., runoff, conservation) of areas not to be irrigated, but within the genera project area. Results of soil profile examinations and laboratory analyses are also put or the map where appropriate. Field surveys are generally supplemented with extensive laboratory analyses, greenhouse studies, and field experimental plot data to obtain as much information as is needed before the irrigation project is implemented. Reports summarizing the data accompany the maps at the various scales. Although the Bureau o Reclamation's irrigation suitability clasification sets up specific limits for classes anc subclasses, the specifications are not absolutely rigid, and can be modified from one project area to another (Olsen 1974).

Soil Mapping Unit Description

Purpose. A soil mapping unit describes the three-dimensional properties of the soil or soils that make up a soil mapping chart, soil topography relationships, and other soil related features that occur on the landscape. The mapping unit becomes the basic unit from which management plans are developed, thus it needs to be accurately defined. Factors that should be included within the description include:

1. Soil composition, i.e., homogeneity of unit;

2. Degree and configuration of slope on which unit occurs;

3. Existing or potential erosion characteristics;

4. Brief description of the physical characteristics of the soils; such as, texture, structure, rainage, depth, permeability, infiltration, and ny chemical characteristics;

5. Identity of native vegetation or type of rop; and

6. Identity of water table relationships if resent.

Following are definitions of types of soil apping units as developed by the Soil Consertion Service, USDA (Soil Survey Staff 1975).

Consociations. — These are mapping units which only one kind of soil dominates each elineation to the extent that three-fourths or ore of the soils fit within the criteria defined r the soil that provides the name for the mapng unit. No one contrasting inclusion may constute more than 10 percent of the unit and the agregate of all contrasting inclusions may not ceed 15 percent.

Complexes. — These are sets of delineated sl areas with two or more important componts in such an intricate geographical pattern tht they cannot be mapped separately at a scale o 1:20,000. The component kinds of soil that pvide the name for the mapping unit have sufficently different use or management requirents for the purposes of the survey that the ut cannot be named as a consociation. Interpretaons may be made for the complex as a whole, dermined by the overriding limitation of any one or a combination of components and the pattern of components. No single inclusion that is dissimilar to any one of the soils providing the name for the mapping unit may exceed 10 percent of the whole and the aggregate of these not more than 25 percent.

Associations. — These are sets of delineated areas in which two or more important kinds of soil or soils and kinds of miscellaneous areas are found in some regular pattern and are individually large enough to be mapped separately at a scale of about 1:20,000. Each delineated body of a soil association has the same major components, and potentials for use and management of the individual areas are about the same. As the intensity of the survey decreases, however, i.e., Order 4 vs Order 3, the relative proportions and distribution of soil components may vary considerably both within the same occurrence and among occurrences of the same association. This is particularly true for older surveys. Thus, the potentials for use and management of the units may vary.

Undifferentiated groups. — These are delineated areas in which two or more similar soils are combined because some phase criteria determines use and management interpretations for the purpose of the survey. The major components are large enough to be separated at the scale of mapping and have no regular pattern. Every delineation has at least one of the major components and may have all. Each of the components need not occur in every delineation, however.

In summary, the purity and homogeneity of mapping units is a function of the level of intensity or detail of a soil inventory. Land managers and planners need to be aware of this fact when using and planning for soil inventories. This is a very important item, because the information contained within a mapping unit description is the basis for making decisions on land management units.

Soil Classification and Correlation

There has been in the past and continues to be disagreement relative to classifying soils by various classification schemes. Most notably, questions are raised regarding the taxonomic

Table 3. — Sample form for soil profile and related information

Soil Type or Designation: File No.

Date	Stop No.	
Classification		
Location		
		Climate
Parent material		
Physiography		
	Drainage	Salt or alkali
Elevation	Gr. water	Stoniness
Slope	Moisture	
Aspect	Root distrib.	
Erosion: Type	Degree:	
Native vegetation (or crop)		
Additional notes		

Hori-zon	Depth	Color			Tex-ture	Struc-ture	Consistence			Reac-tion	Bound-ary	Percent Coarse Fragments >2 mm.
		Dry	Moist				Dry	Moist	Wet			
			non-crushed	crushed								

classification of soils. The soil survey work of the Department of Agriculture is conducted cooperatively with State agencies, other Federal agencies, and with local organizations and groups. These joint efforts collectively are referred to as the National Cooperative Soil Survey. The Soil Conservation Service has leadership responsibilities for the Federal part of these soil surveys. The Soil Taxonomy Handbook Survey (Soil Survey Staff 1975) is the basis for all classification in the National Cooperative Soil Survey. Major considerations for classifying soils taxonomically and/or by interpretive classifications can be described as follows:

1. In order to utilize existing soil characterization and interpretive data, soils must be classified according to systems that have been used in assembling and storing data that has been collected in the past. If existing acceptable soil taxonomic and/or interpretive classification systems are utilized then it is possible to retrieve and utilize existing information in making interpretations.

2. Classification and correlation of soils allows for this information to become part of a soil data bank that can provide information for future utilization by others in other geographic areas. Through time, this will not only begin to decrease the amount of effort in data analysis, but will aid in improving the reliability of interpretations. Soil classification, by either taxonomic or interpretive classification systems, is the key mechanism for knowledge assimilation and transfer.

Sampling

Information relative to considerations that should be kept in mind in sampling for analysis and classification of soil resources is shown in table 4.

Using Existing Soil and/or Land Inventory Data

Soil and land inventories have been carried out by a number of agencies for a number of years. For example, soil surveys made as early as the 1920's are available for some parts of the Western United States.

The purpose of this section is to develop an awareness of the fact that past and existing soil and land inventories have been carried out at different scales of study and/or according to different concepts. This has resulted in soil and land inventory data that in some cases, is applicable to making interpretations for many uses, and in other cases are applicable to a particular use of level of planning. Add to this the fact that soil and land classification procedures and concepts have changed through time even within an agency, and we have a situation where it is critical that existing inventory data needs to be carefully evaluated for its credibility and reliability. Therefore, it is important to determine the intended purpose and concepts of the Survey from the people or agency that conducts it.

If this is not done, the result is that the user may ultimately decide that the inventory is of no value, when in fact it may be useful if properly interpreted by someone familiar with it.

SURFACE HYDROLOGY

Surface water hydrology investigations are undertaken to determine the location, magnitude, and movement of surface water in an area so that a water balance or budget can be developed. The water budget is an attempt to integrate the components of the hydrologic system (ground water, surface water, atmosphere, and soil) into a physical model. This model is used to estimate the system response to land surface modification brought about by surface mining. Other objectives of a surface water investigation are to determine the surface water quality and quantity, its social and economic importance, and its potential impact on the resource and its users.

To achieve these objectives the following information is needed:

1. Detailed location of all surface water features,

2. Topographic relief of the area,

3. Aerial distribution of soils and surficial geology,

4. Vegetation cover and distribution,

5. Magnitude and frequency of precipitation events,

Table 4. – Summary of factors important for consideration in soil characterization and sampling

Determining need:	Samples for laboratory characterization and classification.
Selecting a location:	Duplicate and/or paired profiles should be identified for each of the different soils which occur on a tract of land. Sampling paired profiles minimizes the chance of error. Sites should be representative of the soil in question and located within a mapping unit representative of the soil. Site should also reflect dominant land use.
Sampling procedures:	Bulk samples for laboratory analysis and classification should be taken from each genetic horizon. (A, B & C horizons). Estimates and/or measurements should be made of the amount (by volume) of coarse fragments present. Material sampled for laboratory characterization should include mainly the fine earth fraction i.e., <2 mm. Approximately 5 to 8 lbs. of material is needed for laboratory characterization. Material collected for classification and correlation purposes should include natural aggregates and the amount necessary is normally less than ½ lb. Clod samples can be taken if bulk density and/or mineralogical analyses are to be performed. Samples should be obtained from an open pit. Depth of sampling should be to 60 inches or depth of bedrock if bedrock occurs at <60 inches. Sampling should start with the lowest layer in the pit and proceed upward. Samples of surface soil should include a composite of a number of samples taken from within a mapping unit as well as from the surface material sampled from pits. This will provide an estimate of the mean of the surface soil conditions of the area. A rule of thumb is that one composite sample should not represent an area more than 40 to 80 acres in size. An average of 10 to 15 subsamples per 40 acres should be taken depending on how variable the area may be.
Special considerations:	If NO_3–N is to be determined, samples should be air dried as soon as possible after sampling. Otherwise, the NO_3–N determination more than likely will not reflect existing levels in the soil. Samples taken for heavy metals or micronutrient analyses should be protected from contamination. Rusty tools, galvanized or brass containers should not be used. Brown paper sacks should not be used if boron is to be determined. Plastic bags are most desirable for use. Samples taken for classification and correlation should be separated at time of sampling.

6. Stream flow,

7. Sediment discharge.

A brief discussion of each of these data needs follows.

Location of Surface Water Features

Surface water features include all wet or dry creeks, gullies, ditches, rivers, ponds, lakes, etc. These features should be plotted on 7-½ minute topographic maps (scale 1:24,000). From these plots, determinations of the surface water flow directions, proximity of surface water features to proposed construction sites and appurtenances, and the drainage system morphology can be made. In arid and semiarid regions, surface water bodies often constitute the major source of subsurface recharge. Federal regulations require that recharge on postmining lands be essentially the same as during premining. Thus, it is important that all surface water features be identified and their relationship to subsurface recharge be understood.

The drainage system morphology can provide qualitative insights to the stratigraphy and geologic structure of the area as well as channel response to various precipitation events (Zernitz 1932). Schumm (1977) states that drainage density (the sum of channel lengths per unit area) is proportional to the sediment yield and mean annual runoff. In other words, when subjected to an equivalent precipitation event, areas of dense channel development (common in arid regions) will have higher sediment yields, and greater peak discharge rates than sparsely channeled regions. Drainage density can also be related to the areal infiltration capacity of the ground surface. Low infiltration areas tend to have high drainage densities whereas high infiltration capacity soils tend to have lower drainage densities (Schumm 1977).

Topographic Relief of the Study Area

USGS 7-½ minute topographic quandrangle maps are the best source of relief information. For a given precipitation event, peak runoff rates, sediment transport, and erosion rates are proportional to relief; base flow rates, and rainfall-runoff ratios are inversely proportional to relief.

Areal Distribution of Soils and Surficial Geology

This information may be obtained from geology and soils maps or by field reconnaissance. The following qualitative relationships can be evaluated from geology and soils information:

1. Structural control of the drainage system.

2. High drainage densities are associated with easily erodible materials (Schumm 1977).

3. Low drainage densities are associated with permeable materials (Schumm 1977).

4. High erosion rates and sediment yields exist in areas of easily erodible materials.

In addition, knowledge of the distribution of permeable materials may aid the location of potential ground water recharge areas.

Vegetation Cover and Distribution

Vegetation density may provide insights as to the climate of the area, that is, the magnitude and frequency of precipitation events and drainage system response. In general, sparsely vegetated areas may be indicative of arid climate conditions with high peak flow rates and sediment yields. Densely vegetated areas retard runoff velocities thus reducing sediment yields and peak flow rates while increasing base flow.

Magnitude and Frequency of Precipitation Events

Channel morphology, relief, and vegetation cover, reflect the nature of precipitation over a given area. Arid areas exhibit high relief, rugged topography, and sparse vegetation generally representative of infrequent, torrential precipitation events. On the other hand, humid areas tend to have gentle topography and dense vegetation representative of many moderate precipi-

tation events. In general, sediment load and erosion rates are higher in arid areas than in humid areas. Areas of infrequent, intense storms may have drastic fluctuations of surface water quality in response to the change in flow rate. Areas with extreme discharge and water quality fluctuations require higher monitoring frequencies in order to accurately monitor the hydrologic system. Obviously, higher sampling frequencies lead to greater monitoring costs.

Stream Flow

Stream flow can be determined by the use of chutes, weirs, flumes, horizontal pipes, and velocity measurements; a detailed discussion of these methods follows.

Chutes. — A chute is a steep channel of such high gradient that uniform flow takes place at less than the critical depth (Metcalf and Eddy, Inc. 1972). Flow in chutes is determined by Manning's equation:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

where:

V = flow velocity (ft/sec)

S = slope of water surface (ft/ft)

n = Manning's roughness factor

R = hydraulic radius.

Once the flow velocity is determined, discharge is calculated by $Q = VA$ where A = cross-sectional flow area (width x depth).

Weirs. — Weirs are a very accurate means of flow measurement. This discussion deals with three common weir types; rectangular, triangular, and trapezoidal. The following conditions must be met in order to achieve accurate flow measurements (Albertson and others 1960):

1. The weir plate must be vertical with a smooth upstream face.
2. The crest must be horizontal and perpendicular to the flow direction.
3. The crest should be fairly sharp and free of dents or bends.
4. The channel should be straight with uniform cross-section upstream and downstream of the weir location.
5. The sides of the channel should [illegible] smooth and vertical.

Flow over a rectangular weir can be det[illegible] mined from table 5 or by the following equati[illegible] (Albertson 1960):

$$Q = (3.22 + 0.4\,h/p)\,(L - 0.003)\,(h + 0.003)^{3/2}$$

where:

h = head on the weir (ft)

L = length of the weir crest (ft)

p = height of the weir (ft)

Q = discharge (ft^3/min).

The triangular weir is useful for chann[illegible] with the wide variations in discharge. Flow o[illegible] triangular weirs can be determined from tab[illegible] or with the following equation (Albertson [illegible] others 1960):

$$Q = 2.5\,h^{5/2}$$ (for right-angle notch onl[illegible]

where:

h = upstream water surface height ab[illegible] the weir crest (ft)

Q = discharge (ft^3/min).

Flow over a trapezoidal weir is given [illegible] (Metcalf and Eddy, Inc. 1972):

$$Q = 2/3\sqrt{2g}\,L\,H^{3/2} + 8/15\,Z\sqrt{2g}\,H^{5/2}$$

where:

g = gravitational acceleration (32.2 ft/se[illegible]

L = length of weir crest (ft)

$H = V^2/2g + h$

V = flow velocity over weir crest (ft/se[illegible]

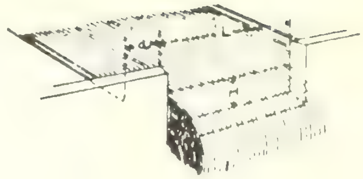
h = upstream water surface height ab[illegible] weir crest (ft)

Z = slope of the side contractions.

Flumes. — Flumes are advantageous [illegible] weirs and chutes because they yield accu[illegible] flow measurements and can be portable. [illegible] though installation is simple, the following [illegible] ditions must be met to insure accurate meas[illegible] ments (Albertson and others 1960):

a. The flume must be set at the pr[illegible] elevation in the channel so that backwate[illegible] drawdown conditions are not created.

Table 5. – Discharge from rectangular weir with end contractions



Head (H) in inches	Length (L) of weir in feet: 1	3	5	Additional g.p.m. for each ft over 5 ft	Head (H) in inches	Length (L) of weir in feet: 3	5	Additional g.p.m. for each ft over 5 ft
	Figures in table are in gallons per minute							
1	35.4	107.5	179.8	36.05	8	2338	3956	814
1¼	49.5	150.4	250.4	50.4	8¼	2442	4140	850
1½	64.9	197	329.5	66.2	8½	2540	4312	890
1¾	81	248	415	83.5	8¾	2656	4511	929
2	98.5	302	506	102	9	2765	4699	970
2¼	117	361	605	122	9¼	2876	4899	1011
2½	136.2	422	706	143	9½	2985	5098	1051
2¾	157	485	815	165	9¾	3101	5288	1091
3	177.8	552	926	187	10	3216	5490	1136
3¼	199.8	624	1047	211	10½	3480	5940	1230
3½	222	695	1167	236	11	3716	6355	1320
3¾	245	769	1292	261	11½	3960	6780	1410
4	269	846	1424	288	12	4185	7165	1495
4¼	293.6	925	1559	316	12½	4430	7595	1575
4½	318	1006	1696	345	13	4660	8010	1660
4¾	344	1091	1835	374	13½	4950	8510	1780
5	370	1175	1985	405	14	5215	8980	1885
5¼	395.5	1262	2130	434	14½	5475	9440	1985
5½	421.6	1352	2282	465	15	5740	9920	2090
5¾	449	1442	2440	495	15½	6015	10400	2165
6	476.5	1535	2600	528	16	6290	10900	2300
6¼		1632	2760	560	16½	6565	11380	2410
6½		1742	2920	596	17	6925	11970	2520
6¾		1826	3094	630	17½	7140	12410	2640
7		1928	3260	668	18	7410	12900	2745
7¼		2029	3436	701.5	18½	7695	13410	2855
7½		2130	3609	736	19	7980	13940	2970
7¾		2238	3785	774	19½	8280	14460	3090

This table is based on Francis formula:

$$Q = 3.33\ (L-0.2H)\ H^{1.5}$$

which

Q = cu. ft of water flowing per second.
L = length of weir opening in feet. (should be 4 to 8 times H).
H = head on weir in feet (to be measured at least 6 ft back of weir opening
a = should be at least 3 H.

Table 6. – Discharge from triangular notch weirs with end contractions

Head (H) in inches	Flow in gallons per minute		Head (H) in inches	Flow in gallons per minute		Head (H) in inches	Flow in gallons per minute	
	90° Notch	60° Notch		90° Notch	60° Notch		90° Notch	60° Notch
1	2.19	1.27	6¾	260	150	15	1912	1104
1¼	3.83	2.21	7	284	164	15½	2073	1197
1½	6.05	3.49	7¼	310	179	16	2246	1297
1¾	8.89	5.13	7½	338	195	16½	2426	1401
2	12.4	7.16	7¾	367	212	17	2614	1509
2¼	16.7	9.62	8	397	229	17½	2810	1623
2½	21.7	12.5	8¼	429	248	18	3016	1741
2¾	27.5	15.9	8½	462	267	18½	3229	1864
3	34.2	19.7	8¾	498	287	19	3452	1993
3¼	41.8	24.1	9	533	308	19½	3684	2127
3½	50.3	29.0	9¼	571	330	20	3924	2266
3¾	59.7	34.5	9½	610	352	20½	4174	2410
4	70.2	40.5	9¾	651	376	21	4433	2560
4¼	81.7	47.2	10	694	401	21½	4702	2715
4½	94.2	54.4	10½	784	452	22	4980	2875
4¾	108	62.3	11	880	508	22½	5268	3041
5	123	70.8	11½	984	568	23	4565	3213
5¼	139	80.0	12	1094	632	23½	5873	3391
5½	156	89.9	12½	1212	700	24	6190	3574
5¾	174	100	13	1337	772	24½	6518	3763
6	193	112	13½	1469	848	25	6855	3953
6¼	214	124	14	1609	929			
6½	236	136	14½	1756	1014			

Based on formula:

$$Q = (C)(4.15)(L)(H)\sqrt{2gH}$$

in which Q = flow of water in cu. ft. per sec.
L = width of notch in ft. at H distance above apex.
H = head of water above apex of notch in ft.
C = constant varying with conditions, .57 being used for this table.
a = should be not less than ¼ L.

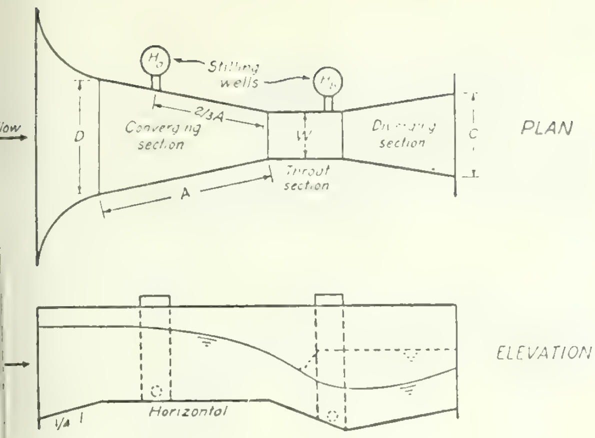
For 90° notch the formula becomes

$$Q = 2.4381 H^{5/2}$$

For 60° notch the formula becomes

$$Q = 1.4076 H^{5/2}$$

—Courtesy Ingersoll-Rand Co.



igure 2. Parshall flume.

b. The flume must be set in a horizontal osition.

c. The flow condition (free or submerged) ust be determined in order to calculate dis-harge.

The following equation may be used to de-rmine discharge through a Parshall flume (see g. 2).

$$Q = 4WH_a{}^{1.522W^{0.026}}$$

here:

Q = discharge (ft^3/min)

W = throat width (ft)

H_a = head for free flow condition, $H_b/H_a < 0.75$ (ft)

I $H_b/H_a > 0.75$ use H_a-H_b in place of H_a. In adition to the above formula, discharge can be culated from rating tables supplied with the me.

Horizontal or inclined pipes. — This method yields approximate discharge rates from hori-zntal or inclined pipes flowing full or partially fed. The method is described in fig. 3.

Stream velocity measurements. — Stream velocity can be used to calculate discharge with th following relation:

$$Q = VA$$

where:

Q = discharge rate

V = flow velocity

A = flow area (width x depth).

Various velocity measurement techniques are discussed below:

Current meters. — The Price current meter is the most widely used velocity meter in the United States. Mean stream velocities are determined by measuring the velocities at the 0.2 and 0.8 flow depths and then averaging. These meters usually yield very accurate results, however, excessive debris of fine suspended sediment in the stream may foul the meter.

Floats. — Floats are a simple, cheap method of determining flow velocity. The float is placed in the stream and its travel distance vs time is measured (velocity = distance/time). Oranges and grapefruit are ideal floats because they are highly visible and float just at the water surface so wind effects are minor. This method can be used only in channels with uniform flow free of obstruction or debris.

Velocity head. — Discharge or velocity measurements are often times difficult in small channels with shallow flow. In these situations the velocity head method provides reasonable discharge estimates. To determine velocity, a ruler is inserted into the channel such that it is perpendicular to the water surface with the broad side normal to the flow. The difference in water level between the upstream and downstream face of the ruler is inserted into the following equation to determine velocity:

$$V = \sqrt{2gh}$$

where:

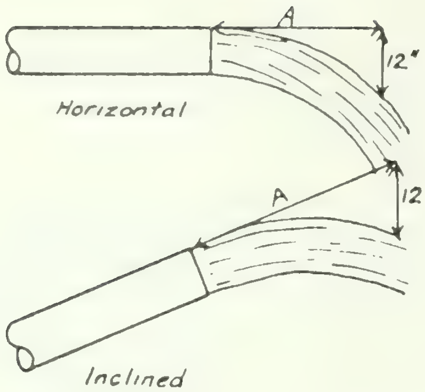
V = velocity (ft/sec)

g = gravitational acceleration (32.2 ft/sec^2)

h = difference in water surface elevation between upstream and downstream face of the ruler (ft).

With practice, this method can yield flow estimates within 20 percent of the actual value, but is not a preferred method.

(FULL PIPES)



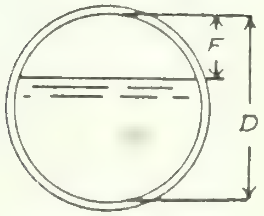
A fairly close determination of the flow from full open pipes may be made by measuring the distance the stream of water travels parallel to the pipe in falling 12 inches vertically.

Measure the inside diameter of the pipe accurately (in inches) and the distance (A) the stream travels in inches parallel to the pipe for a 12-inch vertical drop. (See diagram)

The flow, in gallons per minute, equals the distance (A) in inches multiplied by a constant K obtained from the following table:

I.D. Pipe	K	I.D. Pipe	K	I.D. Pipe	K	I.D. Pipe	K	I.D. Pipe	K	I.D. Pipe	K
2	3.3	4	13.1	6	29.4	8	52.3	10	81.7	12	118.
1/4	4.1	1/4	14.7	1/4	31.9	1/4	55.6	1/4	85.9	1/2	128.
1/2	5.1	1/2	16.5	1/2	34.5	1/2	59.0	1/2	90.1	13	138.
3/4	6.2	3/4	18.4	3/4	37.2	3/4	62.6	3/4	94.4	1/2	149.
3	7.3	5	20.4	7	40.0	9	66.2	11	98.9	14	160.
1/4	8.6	1/4	22.5	1/4	42.9	1/4	69.9	1/4	103.	1/2	172.
1/2	10.0	1/2	24.7	1/2	45.9	1/2	73.7	1/2	108.	15	184.
3/4	11.5	3/4	27.0	3/4	49.0	3/4	77.7	3/4	113.	16	209.

(PARTIALLY FILLED PIPES)



For partially filled pipes, measure the freeboard (F) and the inside diameter (D) and calculate the ratio of F/D (in percent). Measure the stream as explained above for full pipes and calculate the discharge. The actual discharge will be approximately the value for a full pipe of the same diameter multiplied by the correction factor from the following table:

F/D Percent	Factor	F/D Percent	Factor	F/D Percent	Factor	F/D Percent	Factor
5	0.981	30	0.747	55	0.436	80	0.142
10	.948	35	.688	60	.375	85	.095
15	.905	40	.627	65	.312	90	.052
20	.858	45	.564	70	.253	95	.019
25	.805	50	.500	75	.195	100	.000

Courtesy U. S. Geological Survey

Figure 3. Estimating flow from horizontal or inclined pipes.

Sediment Discharge Measurement

Measurement of sediment discharge or the sediment load of a stream is a difficult matter which should be left to a competent hydrologist with adequate experience. Briefly, measurement is accomplished through use of samples which accumulate sediment over a measured period of time. Laboratory studies reveal that at least ten sediment samples per station are required to achieve ±10% accuracy. The following information is required to calculate sediment transport rates (Simons and Senturk 1977):

a. Stream discharge rate.

b. Stream velocity.

c. Cross-sectional flow area.

d. Stream width.

e. Mean sampling depth for suspended sediment.

f. Suspended sediment concentration.

g. Size distribution of channel bed material.

h. Water temperature.

The following conditions must be met in the test reach (Simons and Senturk 1977):

a. The reach should be uniform in shape and sediment composition.

b. No sharp bends, rills, or excessive vegetation in the test reach.

c. No significant tributaries or diversions should join the river within or immediately above the test reach.

Drilling and Sampling Program

DESIGNING A GEOLOGIC OVERBURDEN AND HYDROLOGIC SAMPLING PROGRAM

General

The goals of any overburden and hydrologic sampling program are to obtain data for evaluating the physical and chemical characteristics of overburden material, ground water quality and quantity, and reclamation studies. In addition to obtaining information on these areas of concern the overburden and hydrologic sampling program will also provide data useful in evaluating geotechnical and mineral resource consideration. Geotechnical considerations involve evaluation of the rock characteristics that affect mine layout and pit design. These characteristics include such items as slope stability, floor heave, and the distribution and density of joints, faults, etc. Central to the goals listed above is the conduct of a drilling program which will provide samples and information on the overburden and ground water hydrology. Specifically, answers to the following questions can usually be obtained from the drilling program and from a thorough analysis of the core and/or cutting samples:

What is the thickness, depth, and quality of the host rock containing the mineral resource or the coal seam to be mined?

What is the thickness of the overburden above the mineral resource or coal seam, and the interburden between coal seams?

What is the extent, nature, and distribution of various soils within the exploration boundaries?

What are the rock types and the physical and chemical characteristics of the overburden, interburden, and floor material?

What are the stratigraphic relations (lateral continuity or variability) of the various rock units that constitute the overburden material?

What structural features such as joints, faults, and discontinuities are present that might affect subsequent mining operations?

What are the depths of weathering and mechanical breakdown for specified overburden units?

What are the characteristics of the main water-bearing units in the overburden (e.g., their transmissivity, storage coefficients, leakage coefficients, ground water flow rates, and water quality)?

What will be the impacts of the mining operation on the ground water system and its users?

What will be the impacts of the ground water system on the mining operations?

Drill Hole Spacing and Location

In a recent Environmental Protection Agency report (Smith and others 1976, p. 5) it was recommended that detailed geologic overburden sampling of rock columns down to the coal should be required arbitrarily, at intervals of 1 km (0.6 mi) or less, depending on the rate of lateral change in rock strata. Recommendations of this type are most certainly unwarranted for several reasons.

1. The setting of arbitrary limits on drill hole spacing cannot be justified as such a procedure will not provide the most efficient means of collecting information on overburden, hydrology, geotechnical considerations, and mineral resources.

2. Arbitrary limits cannot be justified on the basis of the great variability in the lateral continuity of rock strata in various basins.

If arbitrary limits are unjustified, it follows that drill hole spacing and location must be determined uniquely for each geologic province or possibly even for each mine site. In making these determinations, several aspects of drilling and sampling theory must be reviewed.

In the first place, it should be emphasized that most programs initiated by mining companies will proceed in a series of stages or phases. Initial drilling may involve only reconnaissance holes with a wide spacing designed to penetrate geologic formations for rock units of potential interest and to provide generalized structural data. If favorable results are forthcoming, additional drilling programs will be designed to locate trends in mineralization. Ultimately, when ore bodies are to be outlined in detail, closely spaced drill holes will be required. This type of exploration program is particularly common in the search for sandstone-type uranium ore bodies. Such a program of successive steps in detecting, outlining, and sampling a disseminated copper-molydenum sulfide deposit is illustrated in fig. 4. Other types of exploration programs may be more common in coal exploration where the general extent and character of major coal reserves is known with greater certainty. In an event, modifications to the exploration progra will certainly occur as the program progresse and as new data becomes available.

One essential element of any sampling desig (pattern of drill holes) is a randomization pr cedure. The notion of random samples distur many scientists who feel that samples should b collected on the basis of scientific judgment. I random sampling, however, scientific judgme can be used in defining a population to be sar pled. Once defined, each potential sample in th population must be given an equal chance of b ing picked. This can be illustrated by a numb of more widely used sampling designs as show in fig. 5.

Assuming the area to be investigated underlain by homogeneous strata, a simple ra dom sampling plan (fig. 5A) can be used. (the other hand, if the overburden rock stra changes say, from sandstones in the northwe to shales and finally to limestones in the sout east portion of the mine area, a stratified ra dom sampling plan (fig. 5B) might be more a propriate. In this case, the areas to be sampl are selected on the basis of scientific (geolog judgment while the exact location of each d hole within an area is selected by some type random process.

A third consideration involved in the desi of a drill hole program involves the type of d ling methods used. The overwhelming major of holes drilled by mining companies will invo the use of rotary drilling methods that prov cuttings or chips of the overburden units but r continuous cores. Although continuous cores preferable from the standpoint of detailed e uation of the overburden, the cost is mu greater. A thorough discussion of drilling a sampling methods is found in the following s tion of this handbook.

Some continuous cores, along with d cuttings and geophysical logs from other d holes, should be sufficient for the analysis of overburden material.

The spacing of continuous cores must based on specific site considerations (e.g., late variability in overburden strata) as determi from studies of cuttings and geophysical lo Finally, unless other considerations such as

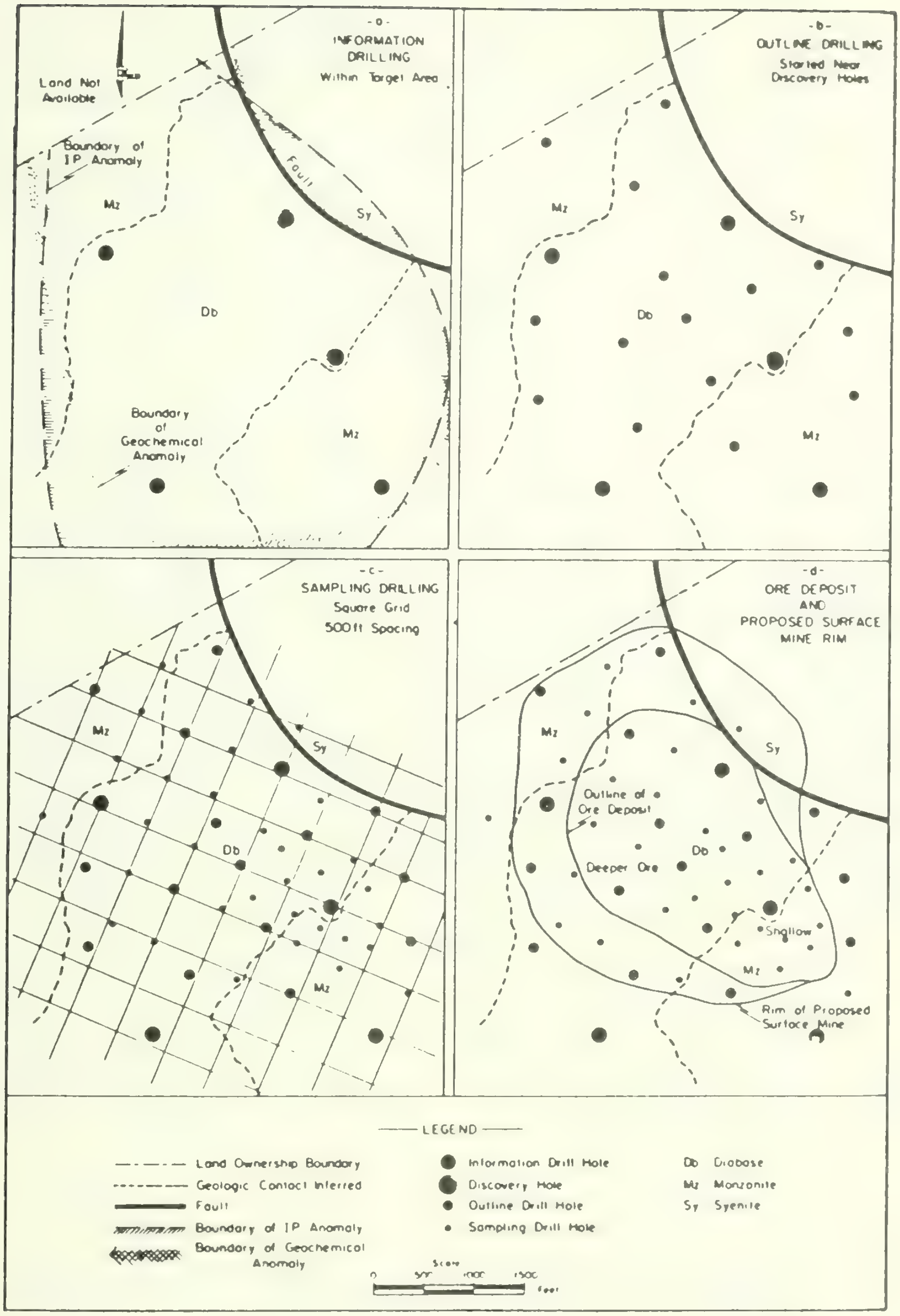


Figure 4. Successive steps in an exploration drilling program to detect, outline, and sample a disseminated copper-molybdenum sulfide deposit (From Bailey, P. A. 1968, fig. 2.1-2, p. 31. Used by permission of the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc.).

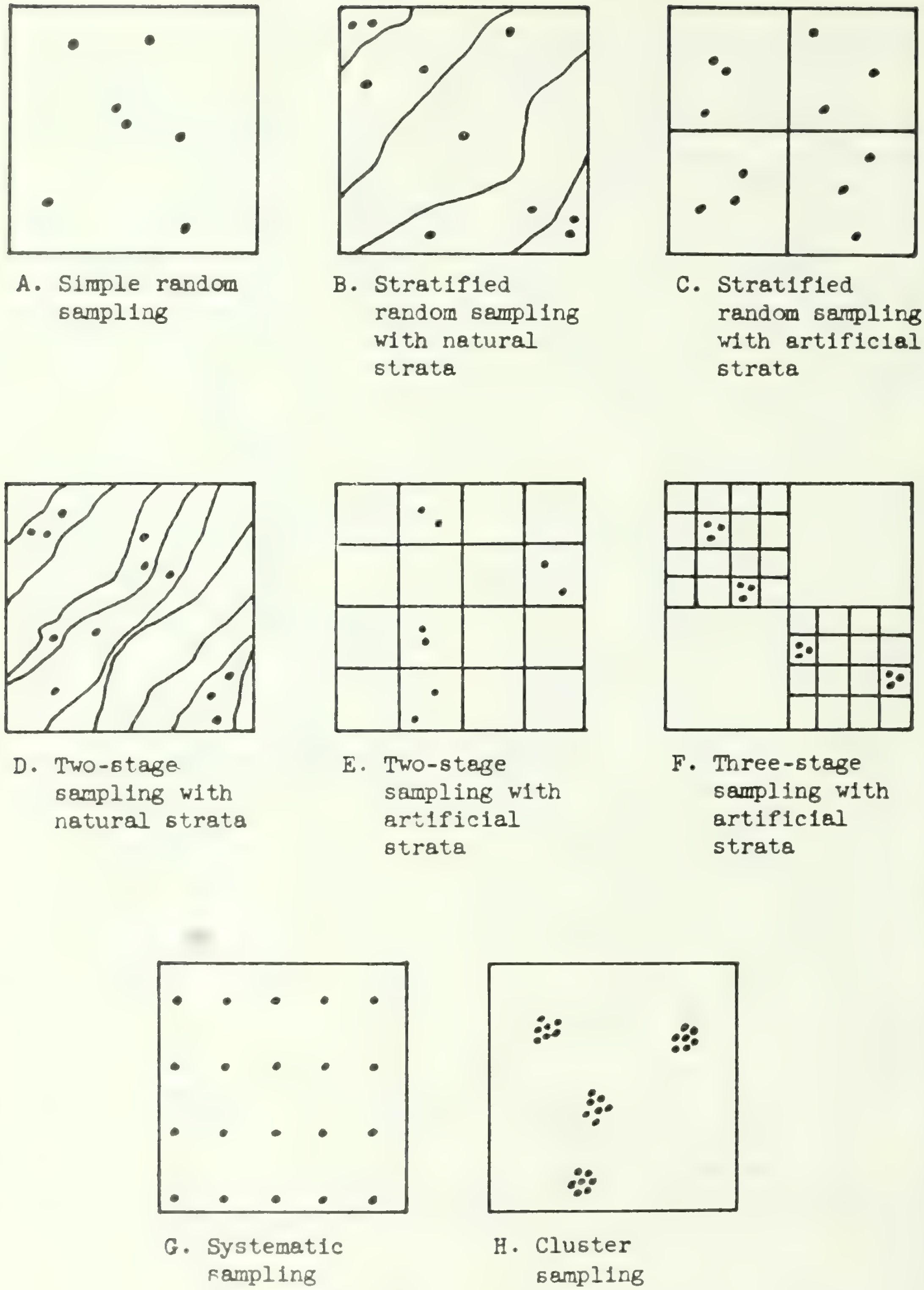


Figure 5. Some of the more commonly used sampling designs. See text for a more complete explanation (after Miesch 1976, fig. 16, p. 83).

:ation of water wells, location of holes to ther geotechnical information, access routes, :., warrant it, the specific location of continus core drill holes should be determined by ndom processes within each area considered to a geologic population.

Two recent reports (Dollhopf and others 78; and Hinkley and others 1978) address the oblem of drill hole spacing for characterizing physical and chemical characteristics of over-rden material at specific sites in Montana. th studies involve an evaluation of the Fort ion Formation which displays considerable eral and vertical variability in both physical d chemical characteristics. Dollhopf and others 78) develop a predictive regression equation t suggests that the drill hole spacing of 76 m 0 ft) allowed for the greatest accuracy in pre-iting overburden characteristics. Their regres-n relationship (Dollhopf and others 1978, p. allows an investigator to determine drill hole cing between 76 m (250 ft) and 610 m (2,000 t based on a trade-off between reliability or ac-acy of the information obtained and the cost drilling operations. This procedure provides a ificant step forward in establishing a geologic rburden and hydrologic sampling program. equation has not, however, been tested out-of the Coalstrip, Montana area or in other ogic strata. Hinkley and others (1978) in a rate study of the Fort Union Formation in tana, state that a single drill hole anywhere a mine site will provide the same information overburden characteristics as many holes. hole spacings used in their study, however, e between 1 and 4 km. At these distances the racy of prediction based on the equation ented by Dollhopf and others (1978) is no er than 50 percent.

anpling Intervals

Smith and others (1976, p. 5) recommend a routine sequential sampling of overburden lmns (from continuous cores) with depth ld require at least one sample representing 0.3 m (1 ft) of overburden from the land ce to the top of each coal to be mined. Fur-hore, they suggest that if samples for analy-e taken by a qualified geologist, the sample val can be extended to 1.5 m (5 ft). This type of arbitrary limitation on the distribution of samples for laboratory analysis is as unjustified as an arbitrary spacing of drill holes.

The type, purpose, and amount of sample needed for a particular analysis must be considered in determining sampling intervals. For example, the amount of core material needed for preparing a thin-section for mineralogical determinations is extremely small compared with the amount of sample needed for salinity, fertility, textural analysis, or plant growth studies in the greenhouse. An arbitrary sampling interval of 0.3 m for thin sections would, undoubtedly, produce redundant data; whereas, the same interval would result in insufficient samples to run other desired chemical and physical analyses.

There are at least two logical ways to approach the method of sampling intervals within a continuous core.

1. The geologic overburden can be divided into rock types (sandstone, shale, mudstone, etc.) and each unit can be sampled according to the thickness of the strata. This type of procedure is generally satisfactory, however, it may provide unnecessary duplication of analyses of the same rock type if it occurs repeatedly in a core. Age differences between the upper and lower portions of a core may, however, justify this repetition as older strata with the same visual characteristics may have different chemical aspects because of diagenetic alterations (alteration of the rock after deposition and burial).

2. A more satisfactory, but also more complicated method of determining sample intervals, involves the recognition of the paleoenvironments of the overburden (i.e., the equivalent modern environment in which a particular stratum was deposited). Once these paleoenvironments are recognized, the strata can be divided into a number of genetically related units (populations), each of which can be sampled for laboratory analyses. The justification of this type of approach can be found in Caruccio et al. (1977, p. 1 and 2). These authors have found that the occurrence of framboidal iron disulfide, for example, within a particular rock strata is a function of its paleoenvironment. That is to say, the conditions under which the rock was deposited control the formation of certain toxic minerals. Thus the association of framboidal

pyrite to certain paleoenvironments (rock sequences) in eastern coals is a key to the identification of rocks associated with coal strata which, when mined, will produce acid mine drainage problems.

The second type of sample interval selection shows great promise for use in the future. There are several problems, however, associated with the use of this plan at the present time. Only some geologists and soil scientists have the training to recognize the paleoenvironments of overburden strata and the relationships which appear valid for eastern coals are only now being tested on western coal bearing sequences. For example, Moran and others (1978) in a study of North Dakota lignite bearing sequences suggest that geochemical variations in overburden materials may be related to the environment of deposition. Unfortunately, they present very little data on correlations to support their statement. Groenewold (1979) demonstrates that an understanding of the original environment of deposition of the overburden material coupled with a well integrated mining and reclamation plan will allow for the design of a postmining landscape in which water chemistry is predictable. The authors of this handbook are currently gathering data from coal bearing sequences in the Powder River Basin to test this contention. No conclusions are available at this time, however.

At this time we, therefore, recommend the first procedure of dividing the overburden strata into rock types on the basis of macroscopic (visual) differences and using these units as sample intervals.

Hydrologic Considerations

In order to evaluate the existing ground water quantity and quality and to determine the impact of mining on the ground water system and its users, a surveillance network must be established that is representative of the system and that provides data concerning the structure, geometry, and hydraulic characteristics of the system. Physically, this surveillance network will consist of a number of monitoring wells, some of which will certainly be used to obtain geologic overburden information as discussed above. With the information obtained from this networ[illegible] will be possible to estimate the system's resp[illegible] to natural and manmade stresses.

The first and most important step in des[illegible]ing a ground water monitoring network is [illegible] identify the purpose and objectives of the m[illegible]toring program. Consideration should be g[illegible] to the fact that monitoring sites located wi[illegible] the area to be mined will be destroyed [illegible] therefore, are only temporary. To provide m[illegible]toring during and after mining, some sites m[illegible] be located outside the area to be mined. O[illegible] this is accomplished, the investigator determ[illegible] the optimum location and number of well[illegible] the network necessary to attain these goals. [illegible] following examples illustrate the relationship[illegible]tween the purpose and pattern of two ideal[illegible] observation networks. For instance, change[illegible] ground water levels and storage volumes are [illegible] observed via an array of randomly spaced w[illegible] (fig. 5A), whereas specific recharge and disch[illegible] locations should be monitored by cluster[illegible] wells in each area (fig. 5H). In both examp[illegible] the number of wells required in the study [illegible] depends upon the complexity of the aquifer [illegible]tem and the level of detail desired (Heath 19[illegible]

The hydrologic characteristics of an aqu[illegible] system are largely determined by the areal [illegible]logic conditions. The geologic conditions [illegible] be incorporated into the design of an obse[illegible]tion network if it is to provide accurate info[illegible]tion concerning the geometry and hydrol[illegible] parameters of the aquifer system. In many a[illegible] the detailed subsurface geology is not kn[illegible] prior to drilling; thus the monitor network [illegible] be flexible so that it may be modified as a[illegible]tional data is obtained during drilling. Pote[illegible] drilling costs may be reduced in situations w[illegible] geologic formations provide information al[illegible] subsurface conditions. The investigator sh[illegible] not be overly reliant on surface relations; h[illegible]ever, in many areas the conditions at depth [illegible] totally unrelated to the topography and geo[illegible] at the surface.

At this point it is useful to examine qua[illegible]tively, the various types of geologic material [illegible] structure with respect to their aquifer chara[illegible]istics and impacts on the monitor network de[illegible]

Unconsolidated formation. — Unconsoli-ated aquifer materials are composed of sand nd gravel zones usually associated with silt and lay. These sediments exhibit intergranular ermeability and water contained in them exists ı pore spaces or the interstices between grains. iravel and sand deposits occur naturally in a ariety of configurations; extensive, continuous hick or thin beds, discontinuous beds and lenses, ringers, and erosion channels.

Monitoring network design is fairly straight-orward in extensive continuous deposits; an ar-y of randomly spaced wells penetrating the me aquifer is sufficient. Discontinuous beds, nses, and erosion channels are a difficult mon-oring problem requiring a detailed knowledge f the subsurface geology. In this case, well spac-g is dependent upon the variability of the quifer deposits; highly variable, discontinuous rmations require a greater monitor well density an continuous deposits. Monitor networks in annelized aquifer deposits should consist of ells placed at regularly spaced intervals along e channel axis. A detailed monitor network in ese deposits would require an extensive drill-ig program at great expense.

Consolidated formations. — Consolidated uifer formations are composed of sandstones hibiting intergranular and/or fracture permea-ity or other rock types with fracture or solu-n channel permeability. Continuous sandstone its with intergranular permeability can be nitored by a network of randomly spaced ells penetrating the same formation. Aquifers th fracture or solution channel permeability y be more difficult depending upon the frac-e or solution channel density. Highly fractured mations may be considered as homogeneous stems on a large scale and monitored accord-ly. Aquifer systems with widely spaced frac-es or solution channels require extensive sub-face exploration before a representative mon-ring network can be established.

Geologic structure. — For our purpose, geo-ic structure includes such features as faults, ds, and bedrock contacts.

Faults may be barriers or conduits for und water movement depending upon the ology and geologic history of the region. lts frequently become ground water barriers due to the formation of impermeable clay gouge zones or by offsetting the aquifer formation until it abuts impermeable deposits. Faults can be ground water conduits when permeable fracture zones are created in otherwise impermeable materials.

Folds have various effects on the ground water flow regime depending upon the type of strata involved and the fold intensity. Localized, discontinuous, perched, and compartmentalized ground water bodies commonly occur in areas of complex geologic structure (Bean 1967).

Ideally a monitoring system should have wells above and below the aquifer in addition to those within the aquifer in order to gain information about the three-dimensional response of the aquifer system to stresses (Heath 1976). The hydrologist must use the disciplines of engineering, geology, hydrology, and economics when designing a monitoring network. In addition, a compromise must be made between the detail produced by the monitor network and its costs.

DRILLING AND SAMPLING METHODS

Drilling

This section mentions the most common methods for drilling, but no attempt has been made to describe the procedure for drilling. Drilling techniques and equipment are described in detail by Acker (1974), Campbell and Lehr (1973), and Johnson (1975). Table 7 summarizes various drilling methods that affect overburden sampling and formation logging; and their affect upon water yield and quality tests. Some recommended drilling methods for various types of geologic overburden are also given in the table.

Sampling During Drilling

Three methods to advance samples during drilling are driving, augering, and rotary core drilling. Drive sampling is used for surficial materials (soils) both above and below the water table. Hammering, jacking, pushing, single blow, and shooting are used to drive samplers into the

Table 7. — Summary of commonly used drilling methods

Method	Recommended overburden conditions	Overburden sampling and formation logging	Water yield and quality te
Cable-tool percussion	Good for fractured or broken formations	Undisturbed cores cannot be obtained; cutting samples are of sufficient size to permit geological identification and description; samples are not contaminated with drilling mud; samples bailed from each interval represent about a 3 to 5 ft zone; when casing is used during drilling there is little chance of sample contamination for caving.	Water bearing zones can be e identified; there is a minimum tamination of water producing z potential aquifers can be te for yield and quality of wat bailing or pumping; permits surement of static water leve
Rotary drilling (direct circulation) using water or drilling mud as the drilling medium	Unsatisfactory or difficult in loose, coarse-grained overburden with cobbles or boulders	Drill cuttings are mixed from different depths and contaminated by drilling mud when used; cuttings brought to the surface can vary with depth characteristics rather than from where the material was penetrated; sample lag time in deeper holes can become troublesome in obtaining a reliable geologic log	Measuring static water levels, t representative water samples performing pump tests of indiv aquifers is not practical; when for drilling water wells the should be drilled using wat drilling additives that are b gradable so that the drilling me can be removed from the well d development.
Rotary-drilling (direct circulation) using air as the drilling medium.	Recommended for highly fractured or cavernous rock such as coal or limestone where conventional rotary drilling would result in the loss of drilling fluids and circulation.	Instant cuttings recovery; as is moisture samples; no washed cores; samples are not contaminated with drilling mud.	Depth to water table can be mined; there is a minimum tamination of water producing
Air-percussion rotary drilling	Best for consolidated rock formations.	Samples are not contaminated with drilling mud.	Depth to water table can b termined; there is a minim contamination of water prod zones
Reverse circulation rotary drilling	Recommended for drilling large holes in unconsolidated formations such as sand, silt, or soft clay		
Rotary drilling with reverse circulation and dual wall pipe	Excellent for drilling and sampling in formations which are highly fractured and/or have voids and cavities.	Produces larger sized chip particles than that of conventional rotary equipment; more accurate and more continuous samples compared to other rotary methods; eliminates sample contamination caused by caving formations or particles eroded from the sides of the hole.	Water aquifers can be ide immediately when drilling wi permits measurement of static levels.
Hammer drilling with reverse circulation and dual wall pipe.	Designed to penetrate alluvial formations, and can penetrate sand, gravel, and boulder formations at rapid speed	Provides a continuous and accurate geological sample of the penetrated material; no critical layers such as soft seams, organic layers, etc., are missed; large cobbles can be lifted without prior crushing	Aquifers can be pinpointed inches because once the dri has progressed beyond the ac the samples become dry aga
Auger boring	This method is best suited for loose, dry, moderately cohesive soils and broken formations which will not easily cave	Obtains representative disturbed samples; generally not satisfactory for obtaining samples below the water table	Water samples are not co nated with any drilling me permits measurement of static levels.
Drive-tube boring	Not satisfactory in coarser fine-grained soils, clean sands, or cohesionless soils below the water table.	Obtains representative disturbed samples.	Water samples are not co nated with any drilling me permits measurement of static levels
Wash boring	Slow in hard or cemented layers.	Representative samples cannot be obtained.	
Jetting	Slow in hard cohesive soils.	No information for formation logging or samples for classification	

l. Rapid continuous pushing using drill rods l the hydraulic cylinders of a drill rig is recommnded for overburden studies.

Auger sampling is used in surficial materials nds, silts, clays) above the water table. Hollow m augers permit sampling below the water le. This method advances the hole with a holy stem auger; when sampling is desired the lling is halted and a drive sampler is passed ough the hollow stem to take samples at the tom of the auger stem. A rotary drill rig can fitted for auger drilling.

Rotary core drilling can be used to obtain k and soil samples. Rotary core drilling is re costly and complicated than drive sampling augering techniques. More variables must be sidered for rotary coring such as coring bits l circulation of a drilling medium such as air, er, or mud.

An improved method of collecting cuttings n a rotary drilled hole using water or water mud as the circulating fluid is described by f and Youngberg (1978). The equipment for ertaking this type of cuttings collection is wn as the Sample Master.

ng Drilling Fluids ring Sampling

During rotary drilling it is necessary to use dlling medium such as air, water, or mud for tg cuttings from the borehole. For overburrstudies it is recommended that air be used e possible. The next recommended choice d be water.

The use of drilling mud should be avoided s absolutely necessary to overcome lost cirion problems, or to lift cuttings from deep , or to support the borehole during drilling. h using mud additives it is recommended a biodegradable mud be used if the borehole e converted into a water well.

Rock cores obtained when using drilling u should be carefully washed before any ical tests are completed on samples. A cal analysis should be obtained on the t and/or drilling mud when used. This analyl be useful when interpreting any chemical s hat might be done on soil or rock samples.

Table 8 shows how various drilling mediums can affect chemical tests.

Prevention of Borehole Caving During Sampling

During drilling and sampling in soft or cohesionless material, the walls and bottom of the borehole can cave. The sides of the borehole can gradually squeeze in if the soil or rock is plastic such as clay material. Casing the borehole with pipe or the use of drilling mud can prevent caving or squeezing in of the borehole.

For overburden studies, it is recommended that the borehole be cased with pipe when drilling materials that can cave or squeeze in. As drilling progresses the drill hole is lined with pipe having an inside diameter which permits the passage of the drill bit to advance the hole and for entry of the sampler. When drilling with rotary systems, the use of drilling mud for supporting the sides of the borehole should be avoided unless absolutely necessary. This will prevent contamination of chemical tests and water aquifers.

Sampling and Rotary Coring Bits

There are a wide variety of coring bits available to drill various geologic materials. Tungsten carbide inserts and sawtooth bits are often used in soils and soft or medium hard rocks because they are less expensive than diamond bits. Diamond bits can be used in soft and medium hard rocks, and are a necessity in hard rocks. Table 9 gives some recommended coring bit designs to be used for various geologic conditions.

Suggested Techniques to Obtain a High Percentage of Core Recovery in Soft or Poorly Consolidated Materials

Good core recovery depends a great deal upon the skill of the drillers who are working with the coring job. The following suggestions can help improve core recovery when used by drillers:

Table 8. — Effects of Sampling Methods on Results of Chemical Analysis of Overburden Samples (adapted from Power and Sandoval 1976)

Drilling methods	Positive aspects	Negative aspects
1. Pneumatic drilling (air), no solutions used, and cuttings blown out of drill hole by compressed air. Samples taken in 1 ft intervals.	Least contaminated, fastest, least expensive.	Solid core was not obtained; difficult to drill when overburden is wet.
2. Coring by circulating water through the drill stem. (Low salt)	Less contamination than with high salt but greater than using Revert.	Lost circulation, soluble salts leached from near surface zone, high cost.
3. Coring by circulating bentonite drilling mud and water through the drill stem. (Mud)		Lost circulation, soluble salts leached from near surface zone, high cost.
4. Coring by circulating water with added sodium and magnesium sulfate through the drill stem. (High salt)		Lost circulation, greater contamination than with low salt, soluble salts leached from near surface zone, high cost.
5. Coring by circulating an organic polymer (Revert) and water through the drill stem.	Circulation was not lost during drilling.	High cost.
6. Highwall samples (used as reference samples)		

1. Keep the weight on the bit low to prevent plugging the ports of the bit, and to prevent core breakage.

2. Use a high rotation speed.

3. Use a face-discharge bit or a pilot bit with narrow kerf.

4. Use a high viscosity drilling mud.

5. Take large sized cores. In general, the larger the core size taken the better the recovery.

6. Keep trash and lost circulation materials out of the drilling water or mud.

Sampling and Coring Techniques

The sampling and coring techniques mentioned in this handbook can be grouped into the following categories: 1) drive samplers, 2) aug[illegible] samples, 3) rotary coring samples, and 4) spec[illegible] techniques. Table 10 gives some guidelines th[illegible] can be used when selecting a sampling techniq[illegible] for soils or rock overburden.

WELL COMPLETION METHODS

Well Construction

Wells can be drilled using any drilli[illegible] method described in this handbook. The drilli[illegible] and construction of wells are described in det[illegible] by Anderson (1967), Campbell and Lehr (197[illegible]) and Johnson (1975). Techniques used succe[illegible]fully in coal studies are described by Moran a[illegible] others (1978).

Table 9. — Recommended coring bit designs (Acker 1974)

Geologic condition	Recommended bit design for best results	Core diameter in inches
SOFT		
Calcite	Pyramid carbide	7/8 to 6
Chalk	Sawtooth	7/8 to 6
Gypsum	Diamond–pilot crown	7/8 to 3 11/32
Limestone	Diamond-large diameter	2 3/4 to 6
Talc	conventional crown	1 1/8 to 2 5/8
Shale	Diamond–face discharge	
MEDIUM		
Claystone	Pyramid–carbide	7/8 to 6
Siltstone	Diamond–pilot crown	7/8 to 3 11/32
Sandstone	Diamond–conventional crown	7/8 to 6
Limestone	Diamond–face discharge	1 1/8 to 2 5/8
Slate		
Coal		
HARD		
Marble	Diamond–stepped crown	7/8 to 3 11/32
Limestone	Impregnated diamonds–	7/8 to 3 11/32
Chert	conventional crown	
Garnet schist		
Granite		
Gneiss		
Garnet mica		
Dolomite		
Quartzite		
Taconite		
Jasper		

Well Casing

The size, weight, and resistance to corrosion of casing should be considered in water well design. Four-inch diameter wells are the smallest size that will handle a submersible pump. Carbon steel casing is highly resistant to soil corrosion, and stainless steel has excellent durability. Plastic casing is used frequently because it is less costly than steel. Polyvinyl chloride (PVC) is used for depths up to 200 ft. Fiberglass-reinforced epoxy pipe has been used for depths up to 300 ft. Plastic well casings are usually not larger than 6 inches in diameter.

Well Screen and Perforated Casing

Wells in unconsolidated materials need openings in the casing to permit entrance of water into the well. In solid rock formations the casing can be left open at the bottom, and water can enter the well through the end of the casing. Well casing can be perforated in the field using torches, saws, or drills. Casing can also be purchased with perforations that were made at the factory.

Well screens are often used in place of perforated casing. Screen can be purchased with open areas ranging from 2 to 60 percent. Well

Table 10. -- Summary of sampling techniques for soils and geologic overburden

Sampling technique	Recommended geologic conditions for best results	Method of penetration	Length of sample held in barrel	Core diameter	Water table influence	Core quality	State of development	Source[1]
"Pocket" solid barrel sampler spoon type	Gravels, sands	Rotate	36 — 60 inches	1 1/2 to 2 1/2 inches	Recovery and quality of sample questionable below	Not core sample; disturbed material	Readily available	Longyear, Joy
"Door" or "window" type sampler	Gravels, sands	Rotate	36 inches	5 inches	Recovery and quality of sample questionable below	Not core sample; disturbed material	Readily available	Joy
Sidewall sampler	Used only when other sampler types fail	Rotate		1 1/2 to 2 1/2 inches	Recovery and quality of sample questionable below	Not core sample; disturbed material	Readily available	Joy
Thin wall "Shelby tube" sampler	Silts, clays	Press	24 — 54 inches	1 7/8 to 4 7/8 inches	Satisfactory below with normal care	Undisturbed core sample	Readily available	Acker, Joy, Longyear, Mobil Drill, Penndrill, Soiltest, Sprague and Henwood
Solid barrel sampler	Sands, silts, clays	Drive or press	60 inches	1 1/2 to 3 inches	Recovery and quality of sample questionable below	Disturbed core sample	Readily available	Joy, Longyear
Split barrel sampler	Sands, silts, clays	Drive or press	12 — 24 inches	1 1/2 to 3 inches	Recovery and quality of sample questionable below	Disturbed core sample	Readily available	Joy, Longyear
Split barrel sampler with liner	Plastic soils	Drive or press	12 — 24 inches	1 7/16 to 2 15/16 inches	Sample recovery and quality questionable below	Disturbed core sample	Readily available	Joy, Longyear
Split barrel sampler "Maine type"	Sands, silts, clays	Drive or press	16 inches	3 1/2 to 5 inches	Sample recovery and quality questionable below	Disturbed core sample	Readily available	Joy, Longyear
Double tube continuous drive sampler	Sands, silts, clays	Drive	60 inches	2 7/8 inches	Sample recovery and quality questionable below	Not core sample; disturbed material	Commercially available on special order	Penndrill
M.I.T. sampler with retainer and piano wire	Clays	Drive	30 inches	5 inches	Satisfactory below with normal care	Undisturbed core sample	Commercially available on special order	Sprague and Henwood
Square tube sampler	Clays	Drive	24 inches	2x2 inches square	Satisfactory below with normal care	Undisturbed core sample	Operational but user fabricated	Wilson (1969)
Wit sampler with membrane retainer	Sands, silts, clays	Drive	12 inches	2 1/2 inches	Relatively trouble free below	Undisturbed core sample	Research and development	Wit (1962)
Delft mud sampler	Sands, silts, clays	Drive	2 inches	30 to 60 ft	Relatively trouble free below	Disturbed core sample	Research and development	Begemann (1961)
Fixed piston, thin-walled sampler (Hvorslev type)	Sands, silts, clays	Drive	36 inches	3 to 5 inches	Relatively trouble free below	Undisturbed core sample	Operational but user fabricated	Mathews (1969)
Free piston sampler	Silts, clays	Drive	24 - 30 inches	2 1/2 to 2 7/8 inches	Relatively trouble free below	Disturbed core sample	Commercially available on special order	Mobile Drill
Hydraulic fixed piston thin-walled (Osterberg type)	Sands, silts, clays	Drive	48 inches	2 3/8 to 4 7/8 inches	Relatively trouble free below	Undisturbed core sample	Readily available	Soiltest
Retractable plug sampler	Sands, silts, clays	Drive	6 inches	7/8 inch	Relatively trouble free below	Not core sample; disturbed material	Readily available	Acker, Mobile Drill, Soiltest, Sprague and Henwood
Stationary piston sampler	Sands, silts, clays	Drive	24 — 54 inches	1 7/8 to 4 7/8 inches	Relatively trouble free below	Undisturbed core sample	Readily available	Acker, Penndrill, Soiltest, Sprague and Henwood
Stationary piston sampler with liner (see Acker)	Silts, clays	Drive	6 — 9 inches	2 3/16 inches	Relatively trouble free below	Undisturbed core sample	Commercially available on special order	Acker
Delft foil sampler	Clays, sands	Push	36 inches	2 1/2 inches	Relatively trouble free below	Undistrubed core sample	Research and Development	Begemann (1961, 1971, 1974)

Table 10. — (Continued)

Sampling technique	Recommended geologic conditions for best results	Method of penetration	Length of sample held in barrel	Core diameter	Water table influence	Core quality	State of development	Source[1]
Foil sampler with rotary coring bit	Sands, silts, clays	Rotate	Up to 36 ft	2 11/16 inches	Satisfactory below with normal care	Undisturbed core sample	Research and development	Broms and Hallen (1971), Fukuoka 1969
Swedish foil sampler	Sands, silts, clays	Push	Up to 70 ft	2 11/16 Inches	Relatively trouble free below	Undisturbed core sample	Commercially available on special order	Sprague and Henwood
Double-tube auger	Silts, clays	Rotate	46 inches	1 1/4 to 2 1/4 inches	Not suitable below water table	Undisturbed core sample	Readily available	Soiltest
Shrouded auger	Sands, silts, clays	Rotate	53 inches	4 1/8 inches	Satisfactory below with normal care	Not core sample, disturbed material	Readily available	Mobile Drill
Open spindle hollow stem auger (moss technique)	Silts, clays, sands, gravel	Rotate and drive combination	Variable	Up to 5 1/2 inches	Satisfactory below with normal care	Disturbed core sample	Readily available	Mobile Drill
Rubber sieeved double tube core barrel	Weakly cemented rock; interbedded hard and soft rock; fractured rock; weak rock	Rotate	20 30 ft	3 inches	Relatively trouble free below	Core sample	Commercially available on special order	Christensen
Denison type sampler	Sands, silts, clays, weakly cemented rock	Rotate	24 — 60 inches	2 3/8 to 6 5/16 inches	Relatively trouble free below	Undisturbed core sample	Readily available	Acker, Soiltest, Sprague and Henwood
Pitcher sampler	Sands, silts, clays, weakly cemented rock; interbedded hard and soft rock	Rotate	36 inches	3 to 6 inches	Satisfactory below with normal care	Undisturbed core sample	Readily available	Pitcher Drilling Co
Large diameter swivel type core barrel, core lifter in inner barrel	Weakly cemented rock, interbedded hard and soft rock fractured rock	Rotate	60 — 240 inches	2 1/8 to 5 15/16 inches	Satisfactory below with normal care	Core sample	Readily available	Acker, Christensen, Longyear, Sprague and Henwood
Swivel type core barrel, core lifter in inner barrel (M-design)	Interbedded hard and soft rock, jointed rock	Rotate	60 — 240 inches	7/8 to 2 13/16 inches	Satisfactory below with normal care	Core sample	Readily available	Acker, Christensen, Longyear, Penndrill, Soiltest
Swivel type core barrel, core lifter in outer barrel (X-design)	Jointed rock	Rotate	60 - 240 inches	7/8 to 2 1/8 inches	Satisfactory below with normal care	Core sample	Readily available	Acker, Longyear, Penndrill, Sprague and Henwood
Swivel type core barrel, retractable triple tube (Australian design)	Weakly cemented rock, interbedded hard and soft rock, strongly fractured rock	Rotate	60 - 120 inches	1 1/8 to 3 11/32 inches	Satisfactory below with normal care	Core sample	Readily available	Triefus Industries, Odgers Drilling
Wireline, double tube core barrel	Weak rock, jointed rock	Rotate	60 — 180 inches	1 1/16 to 3 11/32 inches	Satisfactory below with normal care	Core sample	Readily available	Sprague and Henwood, Acker, Boyle Bros., Christensen Longyear, Reed, Reese
Wireline, double tube core barrel with liner	Weakly cemented rock, interbedded hard and soft rock, fractured rock, weak rock, jointed rock	Rotate	60 — 180 inches	1 5/16 to 3 1/4 inches	Satisfactory below with normal care	Core sample	Readily available	Longyear
Orienting double tube core barrel	Interbedded hard and soft rock, weak rock, jointed rock	Rotate	60 — 120 inches	1 5/8 to 5 7/8 inches	Satisfactory below with normal care	Core sample	Readily available	Christensen
Bishop sand sampler	Sand	Push	15 inches	2 3/8 inches	Relatively trouble free below	Undisturbed core sample	Operational but user fabricated	Serota and Jennings (1957) Bishop (1948)

[1] Sources listed without a date are manufacturers or distributors. Addresses for these manufacturers are given in Appendix IV.

Table 11. -- Methods for developing water wells

Method	Advantages	Disadvantages
Over-pumping	Convenient methods for small wells or poor aquifers.	Not adequate for large wells; will n develop maximum efficiency in a we tends to cause sand to "bridge" in t formation; requires the use of hi capacity pumping equipment.
Back-washing	Can effectively reduce "bridging."	Fine sand, mud, silt, or clay can washed into the well from the form tion; not effective unless combin with surging, bailing, or pumping; lar quantities of water required.
Surge-plungers	Low cost; convenient to use for Cable-tool rigs.	Can produce unsatisfactory results wh an aquifer contains clay because t casing or screen can collapse if it b comes plugged with mud; sometim the well seal can be disturbed wh surging.
Compressed air	Rapid method.	Where yield is very weak and dra down rapid, or submergence is lo other methods will be more satisfacto
High velocity jet	Most effective method; simple to apply.	
Blasting	Rapid method.	Used for solid rock wells only.
Acidizing	Rapid method.	Used for limestone aquifers only.

screens are made of iron, brass, stainless steel, fiberglass, and plastic. The size of perforations, slots, or screen openings are chosen after the particle size distribution of water-bearing zones are determined from samples taken during drilling.

Gravel Packing

Often a drill hole is larger than the outside diameter of the casing so a gravel pack is used to stabilize the formation. The annular space around the well screen or perforations is gravel packed to prevent materials above the water table from caving or slumping into the water producing zone. Gravel packing is also used in unconsolidated formations of fine uniform sand or layered deposits.

Screen openings or perforations are chos so that 90 percent or more of the gravel pa material will be retained. It is recommended th a gravel pack be 3 to 8 inches thick. The gra pack material should be clean, well-round quartz grains.

Well Sealing

Often it is necessary to protect a water p ducing zone from contamination by water fr other aquifers or from the surface by grouti the well. Grouting is accomplished by filling t annular space around the casing with a slurry Portland cement, bentonite, perlite, Gilsoni diatomaceous earth, or other materials.

Well Development

Well development after drilling and casing accomplishes the following: 1) clays, silts, and fine sands are removed from around the aquifer and well; 2) the porosity and permeability of the formation is increased; 3) material around the screens or perforations is stabilized so that the well yields sand-free water; and, 4) clogging and compaction of the formation which occurs during drilling is corrected. Table 11 lists the commonly used methods for developing wells.

GEOPHYSICAL LOGGING METHODS

Well logging is the recording of various geophysical properties of the strata (formations) penetrated by a drill hole. Logging operations are performed by lowering measuring probes or "sondes" into a drill hole on an insulated cable. The measurements are recorded at the surface as the sonde is pulled out of the hole. The recording device at the surface produces a graph of the borehole versus the depth of penetration (fig. 6). Depending upon the nature of the sonde, a number of geophysical properties of the geologic strata and its contained fluids including electrical, radioactive, and acoustical can be measured.

Down-hole geophysical logging methods are well established techniques in the petroleum industry for use in identifying potential reservoir rocks and for determining their porosity and permeability and the nature of fluids present. From the standpoint of overburden analysis an equally important aspect is the ability to identify rock units and to correlate these units between wells. Particular rock formations may yield log curves with distinctive patterns (fig. 6, 7) making it possible to correlate not only major lithologic (rock type) breaks, but many points within the formations themselves (Telford and others 1976, p. 772). Much of the up-to-date methodologies on advancements in down-hole geological logging are found in petroleum related literature. Geophysical logs have been run on a routine basis for years in the petroleum industry and are now being run on a more routine basis than in the past in mining exploration. They hold a great potential for providing geochemical, geotechnical, and assay data from noncored drill holes. The best results are obtained when geophysical logs can be calibrated against core from a cored hole (Dames and Moore 1975, vol. II, p. 92). Principles of geophysical well logging are discussed in chapter 11 of Telford and others (1977) and in chapter 13 of LeRoy and others (1977). The various methods of down-hole geophysical logs commonly used in the evaluation of mineral deposits are reviewed by Scott and Tibbetts (1974). Bond and others (1971) discuss the various well logging techniques used in the coal mining industry and Tixler and Alger (1970) discuss the geophysical log evaluation of nonmetallic mineral deposits. Table 12 (modified from Dames and Moore 1976) presents a list of the more common geophysical logging techniques along with their uses and recommended conditions.

SUBSURFACE HYDROLOGIC MEASUREMENTS

The purpose of subsurface hydrologic measurements is to provide information sufficient to determine the quantity of ground water, direction and magnitude of ground water flow, recharge, and the relationship between ground and surface waters. The configuration of the piezometric surface or water table, hydraulic conductivity, transmissivity, and storage characteristics of each aquifer system are required. Piezometric surface and water table data are determined from static ground water elevation measurements and the hydraulic coefficients are determined from the observation of the time rate of change of ground water elevation during aquifer tests.

Water Surface Elevation Measurements

A permanent reference point, from which all depth-to-water measurements are made, should be established at each well. A notch in the well casing or other indication of a particular reference point will suffice. The elevation of each reference point (measuring point) is established relative to a common datum (preferably mean sea level) with an accuracy of at least 0.1 ft. The depth to water from the reference point is measured and the water surface elevation, rela-

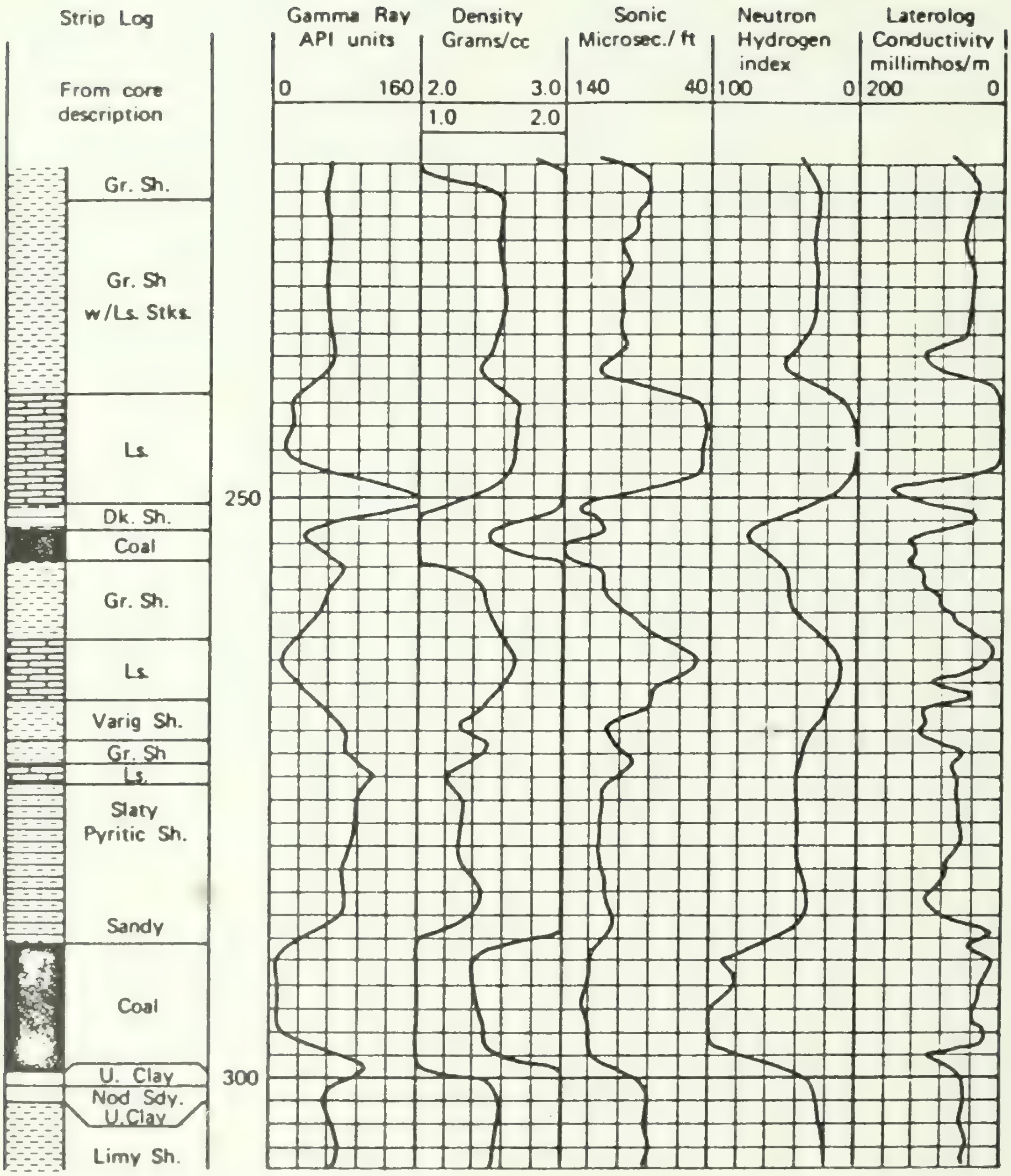
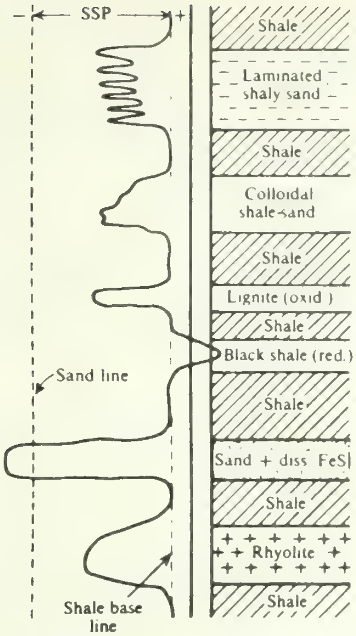


Figure 6. Geophysical log curves from a coal field exploration drill hole showing correlation between various rock types and log shapes (From Jenkins, 1969, fig. 2, p. 11. Used by permission of the American Institute of Mining, Metallurgical and Petroleum Engineers, Inc.).



igure 7A. Characteristics of SP curves for vari-us rock units (after Telford and others 1976, 785).

ve to the datum, is determined. These data are ed to prepare contour maps that depict the cnfiguration of the piezometric surface and/or te water table.

Depth-to-water measurements can be made i a variety of ways (Garber and Koopman 1968; S. Department of the Interior 1977). Static vter levels are conveniently and accurately nasured with a chalked steel tape with a weight aached. The lower end (usually 5 to 10 ft) of t tape is coated with chalk. The chalked portin is lowered into the well until part of the clked portion is wetted by the water standing ir the well. The wetted portion changes shade, pmitting the investigator to determine the distace between the reference point and the water lel. The depth-to-water can be read to a precion of 0.01 ft. Accuracy of the depth-to-water w depend upon the degree to which the tape hgs plumb from the reference point, the temeature relative to the tape's calibration temeature and other factors.

The necessity for withdrawing the tape rn the well for each determination creates a eous disadvantage when several measurements nt be made over small time intervals as in the case of aquifer testing. An electrical or acoustical sounder does not have this disadvantage. An electrical sounder consists of a spool of length-calibrated, insulated electrical cable, a water level sensor, an indicator meter, and a battery. Upon contact with the water surface, an electrical circuit is completed which causes the meter to deflect. The operator raises and lowers the probe slightly to find the exact point of contact with the water surface. The cable is usually calibrated in 5 ft intervals and interpolation between markers with a measuring tape is required. A precision of 0.01 ft can be achieved with practice. Accuracy is substantially affected by kinking of the cable and frequent calibration with a steel surveyor's tape is recommended.

The acoustical sounder consists of a steel tape with a resonator attached to the lower end. The resonator is usually a hollow cylinder about 2 inches long and 3/4 inch in diameter, capped on the upper end. The resonator makes a dripping or popping noise when contact is made and

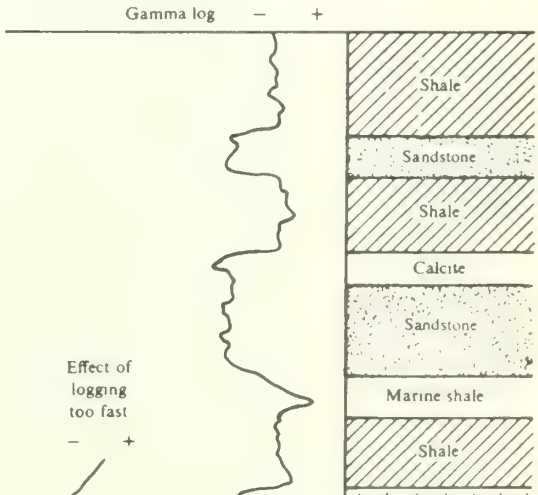


Figure 7B. Typical gamma ray log curve for various rock units (after Telford and others 1976, p. 793).

Table 12. — Standard down-hole geophysical logging methods (modified after Dames and Moore, vol. II, 1976, p. II-94 and II-95)

Method	Uses	Recommended conditions
Electric logging: Single electrode resistance	Determining depth and thickness of thin beds. Identification of rocks, provided general lithologic information is available. Correlation of geologic formations or beds. Determining casing depths	Fluid-filled uncased hole. Fresh mud require Hole diameter less than 8 to 10 inches
Short normal electrode spacing of 16 inches	Picking tops of resistive beds. Determining resistivity of the invaded zone. Estimating porosity of formations (deeply invaded and thick interval). Correlation and identification of geologic formations provided general lithologic information is available.	Fluid-filled uncased hole. Ratio of mud resisti formation – water resistivity should be 0.2 to
Deep lateral (electrode spacing approximately 19 inches)	Determining true resistivity where mud invasion is relatively deep. Locating thin beds.	Fluid-filled uncased holes. Fresh mud. Formati (rock units) should be of thickness different t electrode spacing and should be free of t limestone beds.
Limestone sonde (electrode spacing of 32 inches)	Detecting permeable zones and determining porosity in hard rock. Determining formation factor in sites.	Fluid-filled uncased hole. May be salty mud. U form hole size. Beds thicker than 5 ft
Laterlog	Investigating true resistivity of thin beds. Used in hard formations drilled with very salty muds. Correlation of formations, especially in hard rock regions	Fluid-filled uncased hole. Salty mud satisfact Mud invasion not too deep
Neutron	Delineating formations and correlation in dry or in cased holes. Qualitative determination of shales, tight formations, and porous sections in cased wells. Determining porosity and water content of formations, especially those of low porosity. Distinguishing between water or oil-filled or gas-filled reservoirs. Combined with gamma-ray log for better determination of lithology (rock type) and correlation of formations. Indicates cased intervals. Logging in oil-based muds.	Fluid-filled or dry cased or uncased hole. mations relatively free from shaly material. Di eter less than 6 inches for dry holes. Hole diam similar throughout.
Density	Used as a porosity logging tool. Other uses include identification of minerals in evaporite deposits, detection of gas, determination of hydrocarbon density, evaluation of shaly sands and complex lithologies, and detecting grout	Fluid-filled or dry uncased hole.
Induction logging	Determining true resistivity, particularly for thin beds (down to about 2 ft thick) in wells drilled with comparatively fresh mud. Determining resistivity of formations in dry holes Logging in oil- based muds. Defining lithology and bed boundaries in hard formations. Detection of water bearing beds	Fluid-filled or dry uncased hole. Fluid should be too salty.
Microlog	Determining permeable beds in hard or well consolidated formations. Detailing beds in moderately consolidated formations. Correlation in hard rock regions. Determining formation factor in sites in soft or moderately consolidated formations. Detailing very thin beds.	Fluid-filled uncased hole. Bit-size holes (ca portions of hole only logged if enlargements not great).
Microlaterlog	Determining detailed resistivity of flushed formation at wall of hole when mudcake thickness is less than ⅛ inches in all formations. Determining formation factor and porosity. Correlation of very thin beds.	Fluid-filled uncased hole. Thin mudcake. Salty permitted.
Spontaneous potential	Helps delineate boundaries of formation and the nature of these formations. Determine values of formation-water resistivity. Qualitative indications of bed shaliness	Fluid-filled uncased hole. Fresh mud.
Radiation logging: Gamma ray	Differentiating shale, clay, and marl from other formations Correlation of formations. Measurement of inherent radioactivity in formations. Checking formation depths and thickness with reference to casing collars before perforating casing. For shale differentiation when holes contain very salty mud. Radioactive tracer studies. Logging dry or cased holes. Locating cemented or cased intervals. Logging in oil-based muds. Locating radioactive ores. In combination with electric logs for locating coal or lignite beds.	Fluid-filled or dry cased or uncased hole. Sh have appreciable contrast in radioactivity betw adjacent formations.

Table 12. – (Continued)

Method	Uses	Recommended conditions
Sonic logging	Logging acoustic velocity for seismic interpretation. Correlation and identification of lithology. Reliable indication of porosity in moderate to hard formations, in soft formations of high porosity it is more responsive to the native rather than the quantity of fluids contained in pores.	Not affected materially by the type of fluid, hole size, or mud invasion
Temperature logging	Locating approximate position of cement behind casing. Determining thermal gradients. Locating depth of lost circulation. Locating active gas flow. Used in checking depth and thickness of aquifers. Locating fissures and solution openings in open holes and leaks or perforated sections in cased holes. Reciprocal-gradient temperature log may be more useful in correlation work.	Cased or uncased hole. Can be used in emply hole if logged at very slow speed, but fluid preferred. Fluid should be undisturbed (no circulation) for 6 to 12 hours minimum before logging; possibly several days may be required to reach thermal equilibrium.
	Locating point of entry of different quality water through leaks or perforations in casing or opening in rock hole. Determining quality of fluid in hole for improved interpretation of electric logs. Determining fresh-water-salt-water interface.	Fluid required in cased or uncased hole. Temperature log required for quantitative information.
Fluid-velocity logging	Locating zones of water entry into hole. Determining relative quantities of water flow into or out of these zones. Determining direction of flow up or down in sections of hole. Locating leaks in casing. Determining approximate permeability of lithologic sections penetrated by hole or perforated section of casing	Fluid-filled cased or uncased hole. Flange or packer units required in large diameter hole. Caliper log required for quantitative interpretation. Injection, pumping, flowing, or static surface conditions.
Casing-collar locator	Locating position of casing collars and shoes for depth control during perforating. Determining accurate depth reference for use with other types of logs.	Cased hole
Cement bond logging	Used to assess the quality of the cement-to-using bond around a cemented casing	Cased hole.
Caliper (section gage) survey	Determining hole or casing diameter. Indicates lithologic character of formations and coherency of rocks penetrated. Locating fractures, solution openings, and other activities. Correlation of formations. Selection of zone to set a packer. Used in quantitative interpretation of electric, temperature, and radiation logs. Used with fluid-velocity logs to determine quantities of flow. Determining diameters of underreamed sections for placement of gravel pack. Determining diameter of hole for use in computing volume of cement to seal annudar space. Evaluating the efficiency of explosive development of rock wells. Determining construction information on abandoned wells	Fluid-filled or dry cased or uncased hole. Does not give information on beds behind casing in a cased hole.
Dipmeter survey	Determining dip angle and dip direction (from magnetic north) of a bedding plane in relation to the well axis. A comprehensive study of computed data from a dipmeter survey makes possible the identification of faults, unconformities, cross bedding, sand bars, reefs, channels, deformation around salt domes, and other structural anomalies.	Fluid-filled uncased hole. Directional survey (see below) required for determination of true dip and strike (generally obtained simultaneously with dipmeter curves
Directional (inclinometer) survey	Locating points on a hole to determine deviation from the vertical. Determining true depth. Determining possible mechanical difficulty for casing installation or pump operation. Used in determining true dip and strike from dipmeter survey.	Fluid-filled or dry uncased hole.
Magnetic logging	Determining magnetic field intensity in borehole and magnetic susceptibility of rocks surrounding hole. Studying lithology and correlation, especially in igneous rocks	Fluid-filled or dry uncased hole.

broken with the water surface in the well. The precision of this method is about 0.02 ft. The accuracy is affected by factors previously noted. This method will not be suitable when pump or other noise is sufficient to mask the sound of the resonator.

In cases where the piezometric surface elevation is above the top of the well casing, the well is equipped with a cap that is drilled and tapped in a way suitable for attachment of a pressure gage or mercury manometer. The readings from the pressure gage or manometer are converted to water pressure head and added to the elevation of the measuring point to determine the piezometric surface elevation.

None of the above described methods are suitable for continuous (or nearly continuous) measurements of water levels. Continuous water level records are useful for correlation of water level changes with precipitation and barometric pressure changes. Continuous water level measurements are usually made by attaching a float and a weight to opposite ends of a beaded cable. The cable is suspended over a pulley attached to a drum. As the float elevation changes in response to water level fluctuations, the drum is rotated. The rotation of the drum is recorded by an ink trace on coordinate paper wrapped about the drum. The ink marker is driven laterally along the drum with time by a spring or battery powered clock. A record of the depth-to-water over time is produced. Continuous water level recorders are produced commercially; the Stevens Type F recorder is one example. Independent measurements of the water level should be recorded on the chart each time the chart is changed to insure an accurate starting point for each chart.

Hydraulic Coefficients of Aquifers

Essentially all quantitative studies of ground water require the determination of the capacity of the water bearing materials to store and transmit water. In confined (artesian) aquifers the capacity to store water is characterized by the storage coefficient defined as the volume of water released from storage from a column of aquifer of unit cross-sectional area and length equal to the aquifer thickness when the piezometric head is reduced by one unit (McWhort and Sunada 1977). The storage coefficient is dimensionless number and usually is in the ran of 10^{-6} to 10^{-3}. The storage coefficient for co and overburden aquifers in Colorado, Montan and Wyoming is often about 10^{-5}.

In unconfined (water table) aquifers the c pacity to store water is characterized by the a parent specific yield, defined as the ratio of th volume of water added or removed directly fro the saturated aquifer to the resulting change the volume of saturated aquifer (McWhorter an Sunada 1977). The apparent specific yield is d mensionless and usually is in the range of 0.(to 0.3.

Hydraulic conductivity (also known permeability) is the coefficient in Darcy's la that relates the discharge per unit area in a p ticular direction to the rate of change of piez metric head with respect to distance measured that direction. When the hydraulic conductivi is multiplied by the thickness of the aquifer, th resulting coefficient is called transmissivity.

A large number of field tests have been de vised for the determination of the hydraulic co efficients. The basic idea behind all such tests i to create a flow in the aquifer that can be de scribed mathematically, to measure one or mor aquifer responses to the created flow, and to de termine the hydraulic coefficients by fitting matching the measured response to the theor ical response.

Field tests vary tremendously in regard t expense, time, and data provided. One of th most important determinants of expense is nu ber of observation wells required for the te For example, tests conducted on an individ drill hole are less expensive than full scale aqui tests that require at least one additional well the observation of aquifer response. Nearly a ways, there is a trade-off between the expense the test and quantity and quality of informati obtained.

Table 13 is a summary of several availa test methods that can be used to determine hydraulic coefficients of aquifers. A brief scription of the actual procedures to be follow for each test are contained in the following pa

Table 13. — Summary of aquifer test methods

Test	Reference	Major items required	Parameters obtained	Comments
umping	McWhorter and Sunada 1977; U.S Department of the Interior 1977; Stallman 1971; Walton 1962; Ferris and Knowles, 1963; Ferris and others 1962.	Minimum of one observation well and preferably four or more; pump; power source; winch; tripod, mast or boom; discharge measuring device; stop watch; water level sounder.	T,K,S	Yields parameter values averaged over a relatively large aquifer volume; most commonly used when accuracy and reliability is of high priority; best results in aquifers with good continuity and permeability provided by inter-granular flow channels; can provide evidence of leakage through aquitards, directional permeability, and the presence of hydrogeologic boundaries. Relatively expensive, doesn't work well in very tight aquifers, requires a power source.
raw- own/ pecific apacity	Walton 1970; U.S. Department of the Interior 1977.	Same as above, but no observation wells are required.	T,K	Yields only rough estimates of T and/or K; storage coefficient or apparent specific yield must be estimated independently; conditions immediately adjacent to the well bore, well losses, etc., substantially effect results; in tight aquifers the effects of well-bore storage may be highly important. Relatively inexpensive; most useful in reconnaissance investigations.
ecovery	Same as for pumping test.	Same as for drawdown/ specific capacity.	T,K,S	Recovery should always be monitored following a drawdown/specific capacity test; usually yields more reliable values for T and K than the drawdown/ specific capacity test; has the additional advantage of providing an estimate of storage coefficient or apparent specific yield; because the rate of recovery is dependent upon the preceeding pumping rate the results are effected by well-bore storage. Minimum expense in addition to that incurred during the pumping period and provides additional and more reliable information than the drawdown/ specific capacity test.
ssure mp-in	U.S. Department of the Interior 1977.	Inflatable or compression packers; pump; power source; pressure gages; stop watch; in-line discharge measuring device; storage capacity and source for water.	T,K	Usually conducted during exploration or reconnaissance investigations; permits determination of T and K in different intervals along the well bore; can be used above or below the water table or water level in the well; works best in consolidated aquifers or perforated well casing. Relatively expensive because it is usually conducted during the drilling operations using the contractors rig and equipment.
g/ ing hod	McWhorter and Sunada 1977; U.S. Department of the Interior 1977; Ferris and Knowles 1963; Kvorslev 1951; Papadopulos and others 1967; Bouwer 1978.	Equipment required depends upon the manner in which the slug is added or removed. Pump may be used but is not required.	T,K	One of the simplest and least expensive of all tests; does not require a power source; yields values acceptably accurate for most purposes; analysis procedures available that account for aquifer storage only, well-bore storage only, or both. Applicable in both confined and unconfined aquifers.
A er h	Boast and Kirkham 1971.	Small pump or bail; stop watch; float.	K	Applicable in cases of unconfined aquifers when the water table is within a few feet of ground surface; inexpensive, rapid, reliable.

T = transmissivity;
K = hydraulic conductivity;
S = storage coefficient or specific yield.

graphs. Data analysis procedures are discussed in a subsequent section of the handbook.

Regardless of the type of test selected, the holes must be properly conditioned to insure a free transfer of water to and from the aquifer. This is usually accomplished by surging, pumping, bailing, wall scratchers, or some combination of these procedures. The importance of these operations cannot be over emphasized.

Pumping Test

A pumping test is conducted by measuring the water level drawdown in the pumped well and one or more observation wells in response to pumping at a constant and measured rate. All well construction data should be known in detail. Pumped water must be disposed of so that it does not recharge the aquifer during the test. The duration of the test can range from a few hours to several days. Long test periods usually provide better results but are more expensive.

Observation well location is important, and the projected duration of the test, probable aquifer properties, and whether or not the pumped well is fully penetrating should be considered in the selection of well spacing. In most coal and overburden aquifers in the Rocky Mountain region, transmissivities are small and the cone of drawdown does not expand rapidly. Estimates of the time rate of expansion of the drawdown cone can be made by procedures outlined by McWhorter and Sunada (1977). Rough estimates of pumping rate, transmissivity, and storage coefficient are required. In very tight aquifers, at least one well should be within approximately 50 ft of the pumped well to insure measurable drawdowns within a test period of a few hours. Highly heterogeneous overburden caused by highly variable and discontinuous strata also dictate close spacing of the observation wells. The observation wells should be open for flow only in the stratagraphic interval being tested. When several observation wells are to be used, one-half of the total number should be located on a line passing through the pumped well and the remainder on a similar line at right angles to the first. This procedure may permit detection of directional permeability, for example.

The above described pumping test has b used widely for estimation of transmissivity storage coefficient of aquifers supplying w to industry, agriculture, and municipalities. pumping test becomes less suitable for aqui that exhibit low transmissivities, highly vari and discontinuous stratigraphy, and frac porosity and permeability. Unfortunately, m coal and overburden aquifers in the Rc Mountain region exhibit all of these charact tics, and evenly, properly planned tests l sometimes failed to provide data sufficien justify the expense of such elaborate tests.

Drawdown/Specific Capacity Test

This test is conducted by measuring drawdown in the pumped well during pumping period. The pump discharge mus maintained as nearly constant as possible. Ide the measured drawdowns can be analyze provide estimates of transmissivity and sto coefficient. Usually it is possible to esti only transmissivity, however, and this shoul regarded as only a rough estimate.

In very tight aquifers, a very small disch can be supplied by the aquifer and diffic with adjusting the pump discharge to a sui low value is often experienced. Often, a sub tial portion of the constant pump dischar supplied by the water standing in the well remainder being contributed by inflow fron aquifer. Measurements of the water level in well can be used to determine the contribi from wellbore storage and the pump disch can be corrected to obtain the aquifer disch A good deal of inaccuracy is usually involve

Recovery Test

The recovery test provides estimates o aquifer properties by measuring the reco rate of water levels in the pumped well pumping has ceased. It is especially useful conditions do not permit the construction o servation wells. More precise data can be obt during recovery than during the pumping p because water in the well is not disturbed b pump. Total pumping time, average disc

ite from the aquifer, and the water level at var-ous times since pumping ceased are measured. stimates of both transmissivity and storage co-fficient are obtained.

In the study of ground water at prospective urface mining sites, the recovery test has been ound to be one of the best tests when the infor-ation obtained and costs are compared with ther methods.

essure Pump-In Test

There exist several variations of this test ethod. One variation is to terminate the drilled ole at the bottom of an interval to be tested. he drill tools are removed and a packer is set at given distance above the bottom of the hole. ater is pumped into the test section between s packer and the bottom of the well and the w rate and injection pressures are recorded er a period of time. These data, together with tailed data on depths, test interval, pipe sizes, ., permit the estimation of the average hy-ulic conductivity and transmissivity over the t interval. The packer is then removed, the le deepened, and the test repeated as desired. other variation is to drill the hole to total pth and use straddle packers to isolate intervals interest for testing. The test is started at the tom of the hole.

The pressure pump-in test has been used ensively for foundation investigations associ-d with reservoirs, conveyance facilities, and er construction projects. The method has proven useful in hydrologic investigations, vever.

/Falling Head Test

Briefly, the water level in the well is changed ntaneously by the rapid withdrawal or dis-ement of a volume of water. The water level very in the well is measured with respect to . Slug tests are an economic means of deter-ing local transmissivities near the well. In e types of ground water investigations (tight fers), a large number of "point" transmis-es are of more value than a single value of transmissivity obtained from a long-term pumping test of equal cost (Papadopulos and others 1973). Slug tests can also be an indicator of the effectiveness of well development. In a properly developed well, the slug test transmissivity should be greater than the long term pump test transmissivity (Papadolulos and others 1973).

The following considerations should be made prior to conducting a slug test (adapted from Cooper and others 1967):

1. Wells should be fully developed, that is, surged and pumped thoroughly to establish a good transfer of water between the well and aquifer.
2. Wells should completely penetrate the aquifer.
3. Well construction data should be known in detail.
4. Provisions must be made to quickly remove a known volume of water (by bailer) or quickly displace the water with a "slug". A convenient displacement slug is a length of weighted water pipe sealed at both ends (a 3-inch diameter, 10-ft long pipe displaces a volume of about 0.49 ft^3).

The slug test proceeds as follows:

1. Quickly immerse the slug or remove a known volume of water from the well.
2. Record the time when the slug is immersed.
3. Record the water levels and elapsed time.
4. Make water level readings at 1 or 2 minute intervals for the first several minutes of the test and gradually increase intervals to 10-20 minutes after 1 hour. Half-hour intervals are usually sufficient after 2 or 3 hours.

The falling head test is essentially the same as described above. One variation is to set a packer above the zone to be tested. The head is increased by adding a known volume of water to the stinger pipe extending through the packer. The dissipation of the head is monitored by measuring the water level in the pipe.

Auger Hole Test

This test is useful only when the water table is within a few feet of the ground surface. A hole is augered to a depth that insures the bottom of the hole is a few feet below the water table. A perforated casing is required in materials that tend to cave and bridge the hole. After the hole is cleaned and the water level stabilized, the hole is pumped or bailed dry as quickly as possible. The water level recovery is measured as a function of time, usually by means of a float. The hole depth, hole diameter, depth to the water table, and certain geologic information permit the estimation of hydraulic conductivity. This test is most useful in shallow water table aquifers associated with streams or in perched aquifers.

The above descriptions are provided to give the reader, unfamiliar with such tests, sufficient insight to decide what test or tests may be suitable for a particular problem given a set of financial, time, and equipment constraints. The references provided in table 13 should be consulted for additional details.

Laboratory and Greenhouse Studies

SOILS AND GEOLOGIC OVERBURDEN CHARACTERIZATION

Stratigraphic Framework

Core Descriptions — Lithologic Logs

Continuous cores or rock chips and cuttings from bore holes that penetrate the overburden should be described and lithologic logs prepared by qualified geologists or soil scientists. Drillers logs of each borehole may be available; however, reliance should not be placed on these as satisfactory core descriptions. Information contained in these lithologic logs should include at a minimum: project number, core hole location, core hole number, depth from the surface, rock name, color, texture, accessory constituents (gypsum, pyrite, iron oxide, calcite, etc.), percentage lost core or intervals of lost or broken core, ducation, and general descriptions of each r unit. A simple lithologic log used for descript of cores for the SEAM study site in the Pow River Basin is included (fig. 8). Most mir companies have standard formats for core l These formats will vary from company to c pany. Recently, several computer oriented mats have come into use (Blachet and God 1972; Eckstrom, Wirstam, and Larsson 19 Godwin and others 1977; Chun 1978; Winczew 1978; Melton and Frem 1978; Lehmann 19 Winczewski 1979 a, b). With these methods m of the logged data can be processed by compu and graphically displayed in a standard forma

A color photographic or color slide rec of all cores should be made as a permanent rec of the cores as soon as possible after core covery (fig. 9). Samples from continuous c or cutting should be taken for detailed laborat studies of mineralogy, texture, and geochemi of each major rock unit encountered as discu in the section prior to this. Core samples may be required for geotechnical data such as strength of intact rock, discontinuities, hard and abrasion, blastability, rippability, and ger visual assessment of likely engineering beha of the materials (Dames and Moore, vol 1976). Most of this type of information only be obtained from cores, whereas it is sible to obtain some stratigraphic data from tings alone.

Stratigraphic Studies

Definition and importance. — Stratigr is that branch of geology that deals with study and interpretation of stratified and mentary rocks and with the identification scription, sequence (both vertical and horizon mapping, and correlation of stratigraphic units (Weller 1960). Stratigraphic seque range from simple, where rock units under an area are uniform in thickness and chara to very complex, because of lateral chang rock type, thickness, presence of unconform and/or intense structural implications. An u standing of the stratigraphic framework o overburden is of fundamental importance t design of open pit mines, the handling of

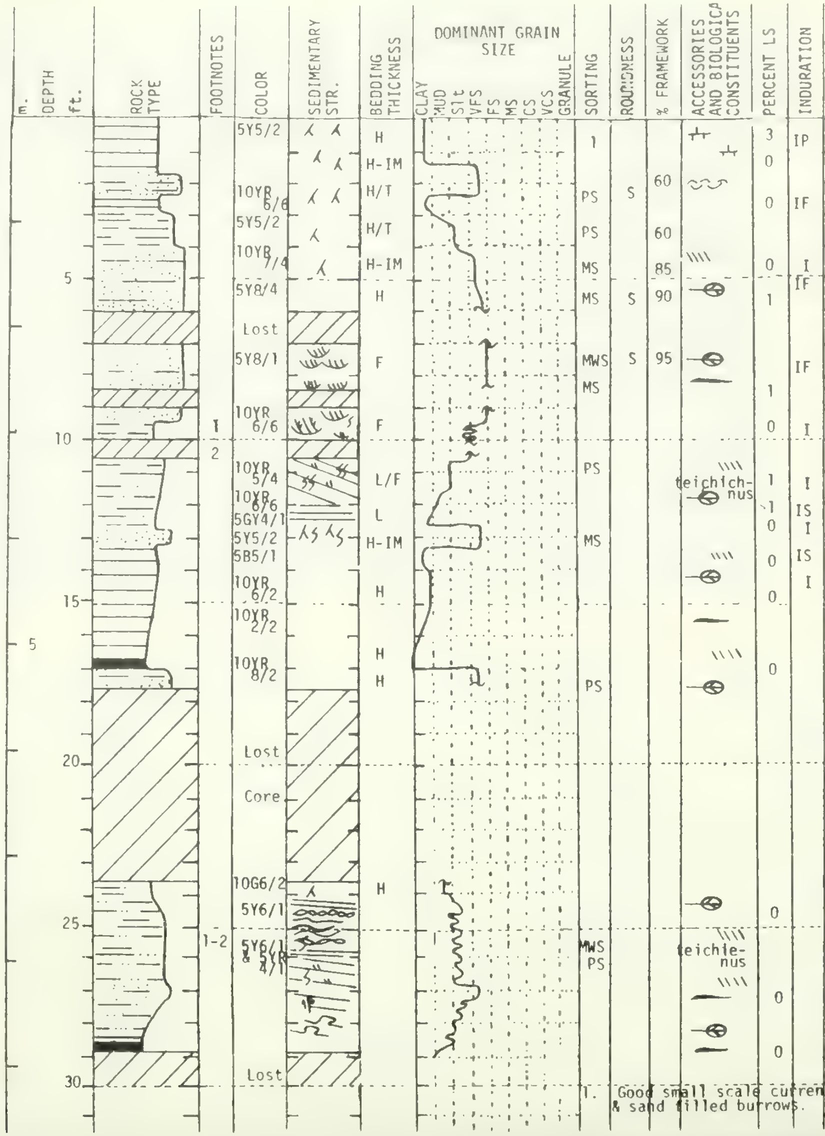
PROJECT NAME: SEAM-POWDER RIVER BASIN

DEPTH: FROM 0 FT. TO 30 FT.

LOCATION: T ____ R ____ S 33, S.W. CORNER E ½

HOLE NO: 29

BOX NOS.: 1, 2, 3



DESCRIPTION

Light olive grey sandy clay w/grass roots, calareous intergrowths (caliche)

@ 1', mottled dusky yellow and dusky brown due to limonite and organic matter - non calcareous. Grades into

Dark yellowish orange (limonite) silty, clayey very fine grained sandstone. Then grey claystone w/limonite stained fractures grading down into very clayey siltstone

Greyish orange, silty, very fine grained sandstone with minor gypsum nodules.

Greyish yellow very silty fine grained sandstone clay cemented.

Lost Core

Yellowish grey, silty, fine to very fine grained, moderately well sorted sandstone w/small scale trough x-beds

Lost Core

Yellowish orange sandy siltstone w/clayey, organic partings. Small scale trough x-beds w/superimposed ripples - burrowed

Yellowish brown clayey siltstone - Parallel laminae draped over a dipping surface. Some micro-x-bedding, silt filled vert. burrows, w/ teichichnus in lower part. Coarsening upward.

Light olive grey very fine grained moderately sorted sandstone w/ roots, lesagane stains, manganese stains.

Bluish grey claystone w/abundant plant fragments.

Pale yellowish brown silty claystone w/abundant leaf frags.

Subbituminous clayey coal.

Pale orange very clayey, very fine grained sandstone w/ abundant wood & leaf fragments.

Lost Core.

Pale green clayey siltstone w/plant fragments & limonite stains.

Light olive grey clean & clayey siltstone, interbedded as horizontal to ripple trough x-laminated, i.e. horizontal, wavey & lenticular laminated. Burrowed, limonite stains, fines upward

Light olive grey and brownish grey clean & clayey siltstone. Dipping parallel lamination (15°) w/ripple lamination, sandfilled burrows and growth faults. leaf frags on bedding planes.

Coarsens upwards from a very organic silty claystone.

-Very clayey lignitic coal.

Lost Core

1. Good small scale current x-bed structures & sand filled burrows. 2. Good burrows.

INFERRED ENVIRONMENT OF DEPOSITION: CR; FDS; CR; WDS

SAMPLE NO AND TYPE

codes for abbreviations and ... Appendix II

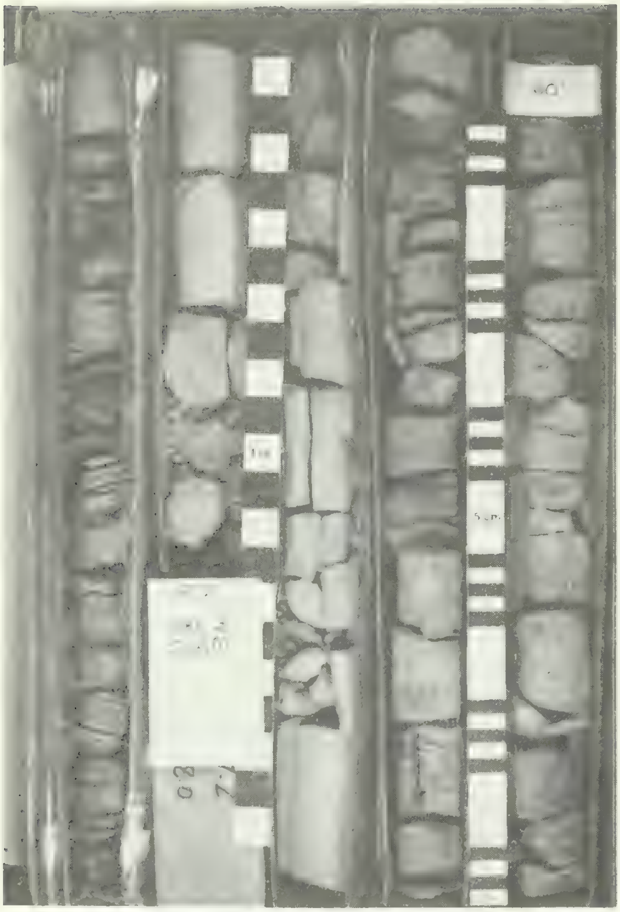


Figure 9. Core from SEAM study site, Powder River Basin, Wyoming.

sirable and/or toxic materials, the design of reclamation plans, and the understanding of ground water flow patterns.

Methods. — Determining the stratigraphic framework of the overburden can be accomplished by evaluation and correlation of some combination of the following down-the-hole records of overburden material: geophysical logs, drill hole cuttings, and continuous cores. The stratigraphic framework cannot be determined on the basis of geophysical logs alone. In areas where no drill hole cuttings or cores are available, outcrop and/or highwall descriptions will provide information for determining the stratigraphic framework of the overburden. Examination of core or cutting data in the field or laboratory provides direct information concerning the physical characteristics of the overburden and provides the basis for interpretation of geophysical logs. Once the relation between geophysical log patterns and lithologies has been substanti the logs become more dependable tool interpreting overburden lithologies.

When all the information from cores tings, and/or geophysical logs is assemblec thickness, elevation, distribution, geometry variability of the overburden and various units within the overburden can be portray some combination of the following visual niques: isopach maps, cross-sections, fenc grams, and structural contour maps.

An isopach map is a map in which the (distribution, thickness) of a body (a rock is indicated by lines drawn through poir equal thickness. The lines are analogous tc tour lines but represent thickness rather elevations or altitude. A typical isopach m shown in fig. 10. Isopach maps are usefu only in showing the total thickness of overb and interburden units within the overbu but can also be used to show the lateral var in content of some toxic element withi overburden if thickness measurements a placed with percentage or parts per thou million, etc., values.

A cross-section is a profile portraying terpretation of a vertical section of the eai this case the overburden) (fig. 11A). A fenc gram is a combination of three or more ge cross-sections showing the relationships of to subsurface formations (rock units). several sections are used together they f fencelike enclosure, hence the name (fig Cross-sections and fence diagrams are usef displaying the two and three dimensiona tudes, thicknesses, and distributions of v rock units within the overburden and the stratigraphic framework of the area of a prc surface mine.

A structure contour map is a map disp contour lines drawn through points of equ vation on a strata, key bed, or some other h in the overburden in order to depict the at of the rocks (fig. 12). Such maps will ce be required of the top and possibly the b of all coal seams to be mined in surfac mining operations.

The number and type of stratigraphic cross-sections and fence diagrams will of be a function of the complexity of th

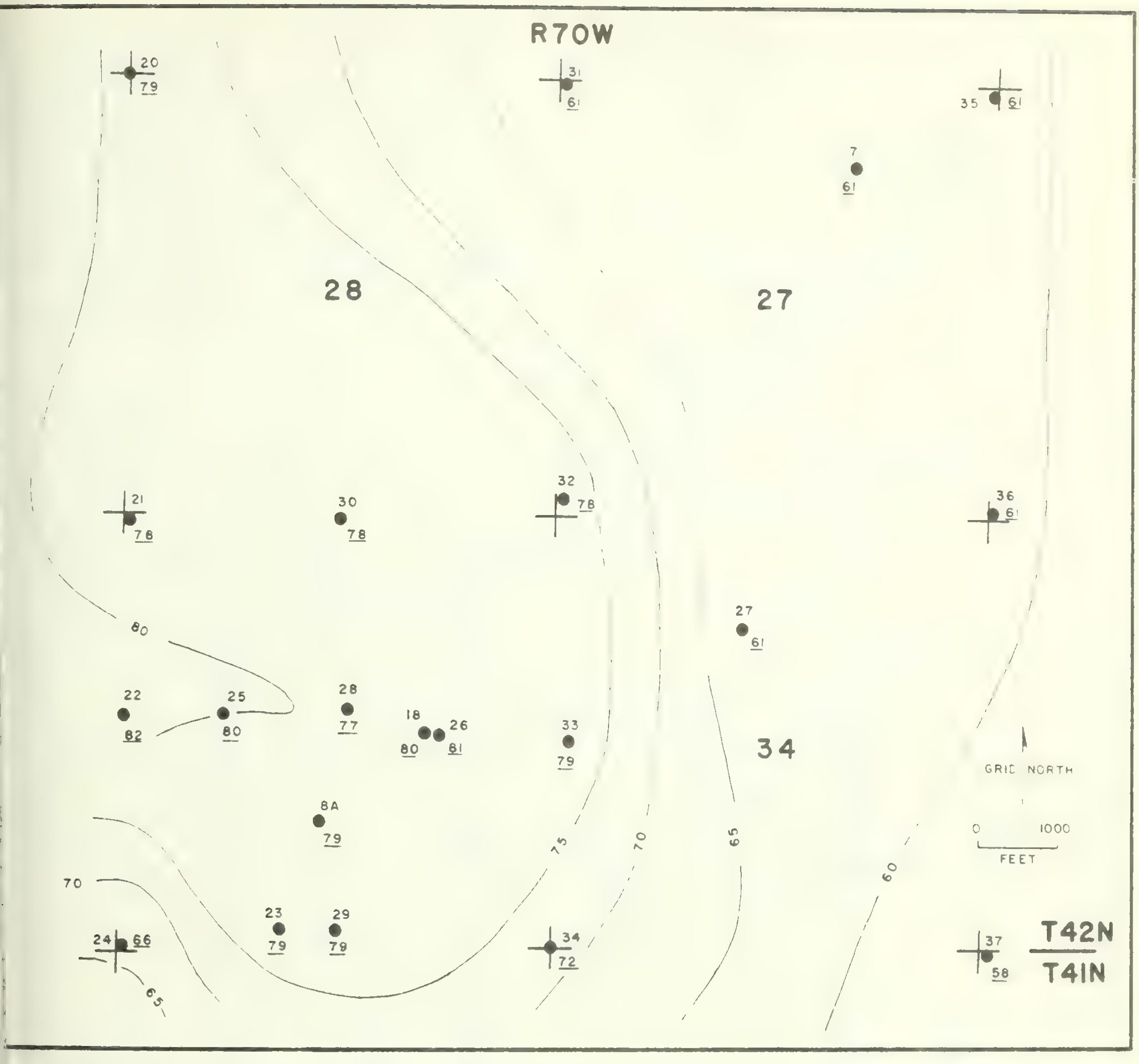


Figure 10. Isopach Map of Anderson Coal Bed, SEAM Study site, Powder River Basin, Wyoming. Thicknesses in feet at each control point are underlined. Contour interval is 5 feet. Interpretation of !sopach Map is found in vol. II of this report.

stratigraphic framework. It seems likely, however, that at least some of these methods will be employed to convey a visual picture of the stratigraphy of the geologic overburden material and the presence and distribution of units that have undesirable characteristics or toxic materials. It should be emphasized that the validity of these maps, cross-sections, etc., is a function of the local stratigraphic complexity, the spacing of drill holes, and the ability of the geologist to recognize key beds or horizons in each drill hole.

Analyses of Soils and Overburden Samples

General

The most prevalent problems reported to occur in relation to strip-mine reclamation in western arid-land areas are: (1) shallow topsoil depths and low fertility status of topsoil, subsoils, and overburden; (2) excessive soil salinity and

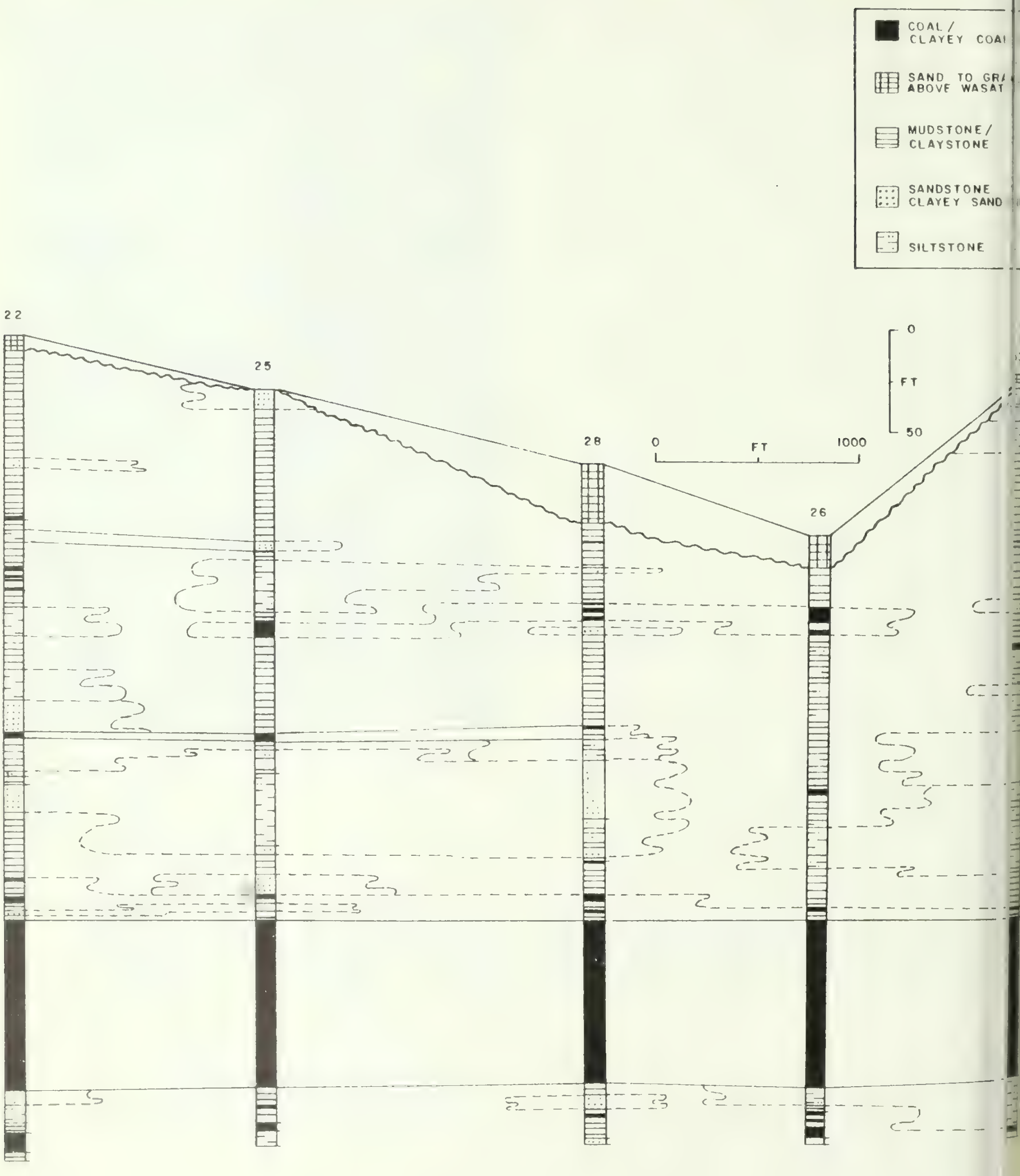


Figure 11A. East-West stratigraphic cross-section across southwest portion of SEAM Study Site, South-Central Powder River Basin, Wyoming. Line of cross-section can be seen by noting location of wells on fig. 10. Interpretation of cross-section is found in vol. II of this report.

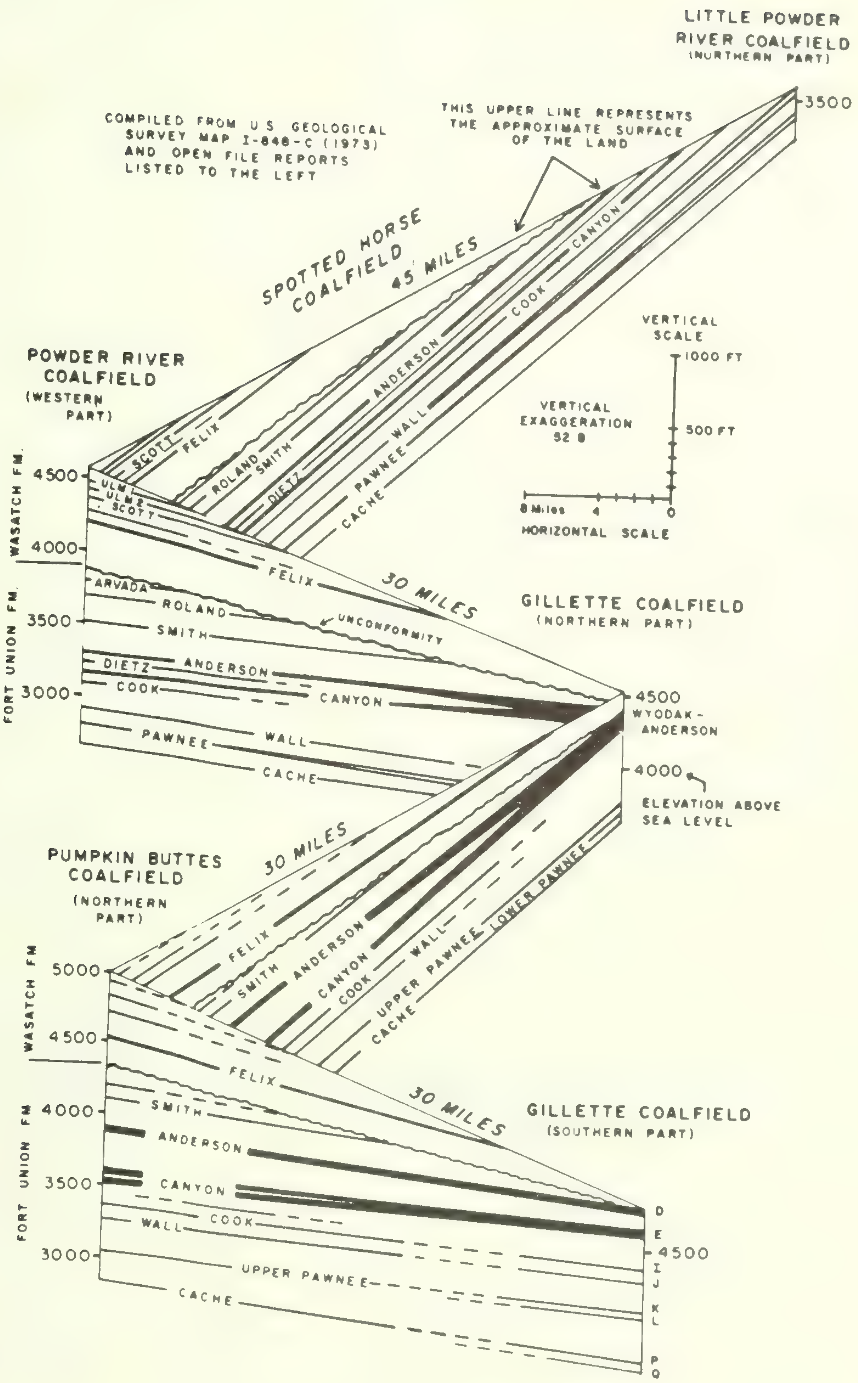


Figure 11B. Fence diagram showing correlation and thickness of major coal seams, Campbell County, Wyoming (after Breckenridge, Glass, Root, and Wendell 1974).

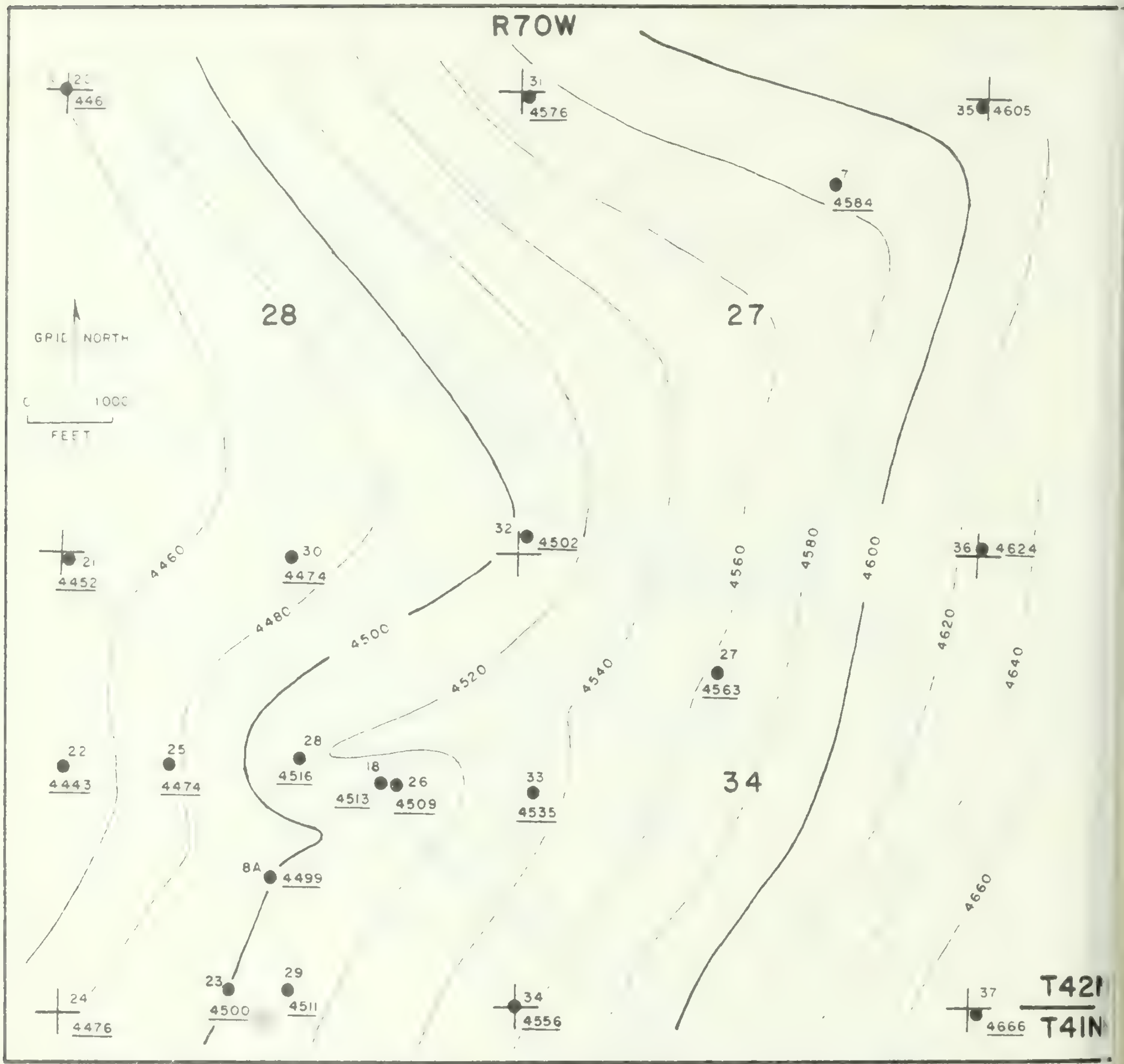


Figure 12. Structure contour map drawn on the top of the Anderson coal bed, SEAM study site, Powder River Basin, Wyoming. Contours are given in feet above sea level. Contour interval is 20 ft . Elevations in feet at each control point are underlined.

exchangeable sodium in soils and overburden; and (3) high clay content of subsoils and overburden. Therefore, the analyses listed in table 14 center around characterizing soil and overburden for these problems. In most cases, the same analytical procedures may be used for both soil and overburden samples. Soil samples should not be taken from cores or cuttings used for overburden characterization, however. Soils should be described and sampled in characterization pits (see page 12 and table 4).

Most of the analyses listed are well-tes and standardized. Thus, the procedures are lis as "acceptable." One procedure source is lis in most cases, a source that is readily available accessible. It is not intended to restrict the a lytical methods or instrumentation used exac to those used in the procedure cited. Any a lytical instrument or method is acceptable gives comparable or more accurate results or correlate well with the procedures cited.

Table 14. – Analyses for characterizing soil and overburden samples

Soil or overburden	Reported as	Importance of and/or use	Acceptable procedure[1]
Salinity-Exchangeable Sodium-Related Analyses and Calculations:			
Saturated paste	Water saturation (SP)	Measure of maximum moisture retention of pulverized (<2 mm) soil or overburden; 1/2 SP gives an estimate of field capacity of unconsolidated material; 1/4 SP gives an estimate of wilting point of unconsolidated material.	USDA Agric. Handb. 525, No. 2, p. 4-6.
Reaction (acidity or alkalinity)	pH of saturated paste (pH_s); pH of dilute soil: water suspension, usually 1:5 (pH_d); pH is the negative log of hydrogen in activity.	Soil pH aids diagnosis of many different soil problems, such as an indication of free lime or excessive exchangeable sodium; pH is not very reliable when used as the only diagnostic criteria.	USDA Agric. Handb. 525, No. 4, p. 6.
Electrical conductivity saturated paste extract	mmhos/cm 2 25°C ($ECx10^3$	Rapid measure of water soluable salt content.	USDA Agric. Handb. 525, No. 1, p. 22.
Water soluable cations (Ca, Mg, Na, K)	meq/l, p/m meq/100 g	Indication of cation distribution in soil solution and on cation exchange complex; assessment of salinity and fertility relationships.	USDA Agric. Handb. 525, No. 2, 3, 4; p. 24-27.
Sodium adsorption ratio (SAR)	$\frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$ (calculated in me/1)	Estimation of percent exchangeable sodium (ESP).	USDA Agric. Handb. 60, No. 20b, p. 102.
Potassium adsorption ratio (PAR)	$\frac{K}{\sqrt{\frac{Ca + Mg}{2}}}$	Estimation of percent exchangeable potassium (EPP).	USDA Agric. Handb. 60, No. 20b, p. 102.
Water soluble anions (CO_3, HCO_3, SO_4, C1, NO_3, B)	meq/l, p/m; meq/100 g	Indication of anion distribution in soil solution; assessment of salinity-fertility relations.	USDA Agric. Handb. 525, No. 5, 6, 7, 11, 12; p. 16-18, 20-22, 27-30.
Ammonium acetate extractable cations (Na, K)	meq/100 g	Determination of exchangeable sodium and potassium.	USDA Agric. Handb. 525, No. 5, p. 7-8.
Cation exchange capacity[2] (CEC)	meq/100 g	Measure of total cation retention.	USDA Agric. Handb. 525, No. 5B, p. 8-9.
Exchangeable sodium percentage (ESP)	Percent	Measure of percent sodium on cation exchange capacity (not reliable for material containing sodium-zeolite).	USDA Agric. Handb. 525, No. 6, p. 9.
Exchangeable potassium percentage (EPP)	Percent	Measure of percent potassium on cation exchange capacity.	USDA Agric. Handb. 60, No. 20, p. 101.
Gypsum	meq/100 g; percent	Measure of solid phase gypsum content.	USDA Agric. Handb. 525, No. 7, p. 10-11.
Fertility-related analyses:			
Calcium carbonate equivalent	Percent; meq/100 g	Measure of alkaline-earth carbonates.	USDA Agric. Handb. 525, No. 3, p. 6.
Organic carbon[3]	Percent (readily oxidized carbonaceous residue of plant material).	Assessment of N and S fertility; stability of soil aggregates.	USDA Agric. Handb. 525, No. 8, p. 12-13.
Total nitrogen	Percent, p/m	Assessment of N-cycling potential in terms of C/N.	USDA Agric. Handb. 525, No. 10, p. 14-16.
Acid permanganate oxidizable soil nitrogen	p/m	Assessment of potentially mineralizable soil nitrogen.	Stanford and Smith, 1978.
Ammonium, nitrate and nitrite	p/m, meq/100 g	Indication of plant available nitrogen.	USDA Agric. Handb. 525, No. 10B, p. 18-20.
Available phosphorus	p/m	Plant availability index.	USDA Agric. Handb. 525, No. 9, p. 13-14; Watanabe and Olsen (1965).
Available potassium	p/m	Plant availability index.	ASA Monograph No. 9, Part 2. Pratt (1965), p. 1027-1030.
DTPA extractable zinc, iron, manganese, and copper	p/m	Plant availability index.	Lindsay and Norvell (1978).

Table 14. — (Continued)

Soil or overburden	Reported as	Importance of and/or use	Acceptable procedure[1]
Toxicity-related analyses:			
Active sulfides (qualitative)	Present or absent	Acidification potential.	Neckers and Walker (1952).
Total sulfur	p/m, percent	Assessing acid-base potential.	ASA Monograph No. 9, Part 2. Bardsley and Lancaster, 1965, p. 1103-1108; Steinbergs, and others. (1962).
Acid-base account	Tons per 1,000 tons	Assessment of neutralization of potential acidity by lime.	Smith and others, (1976), p. 293[4]
Elemental analysis	p/m, percent	Screening for potential heavy metal or other elemental toxicity.	X-ray Spectroscopy, ASA Monograph No. 9, Part 2 Vanden Heuvel (1965), p. 771-819.
Hot water soluble Se	p/m	Assessment of plant toxicity.	ASA Monograph No. 9, Part 2 Fine (1965), p. 1122.
Ammonium oxalate extractable MO	p/m	Assessment of plant toxicity.	ASA Monograph No. 9, Part 2 Reisenauer (1965), p. 1054.
Hot water soluble boron	p/m	Assessment of B-toxicity.	USDA Agric. Handb. 525, No. 12, p. 20-22.
DTPA extractable zinc, iron, manganese, copper, cadmium (and probably other heavy metals.	p/m	Assessment of ion toxicities to plants.	Lindsay and Norvell (1978); Korcak and Fanning (1978).
Physical analyses:			
Particle size analyses	Percent sand, silt, clay (also very fine sand)	Assessment of erosiveness, permeability, water holding capacity, capillary potential inherent fertility.	ASA Monograph No. 9, Part 1 Day (1965), p. 545-566.
Texture	sand, loamy sand, sandy loam, loam, silt loam, sandy clay loam, silty clay loam, clay loam, clay	Assessment of generalized moisture, fertility, and salinity relations.	USDA Texture Classification.
Shrink-swell	Low, medium, high	Assessment of permeability hazard.	ASA Monograph No. 9, Part 1 Holtz (1965), p. 461-63.
Slaking test	Percent particles passing screen	Assessment of induration.	Modification of Smith and others, (1976) vol. 2 (this report).
Mineralogical analyses:			
Pyrite identification	Euhedral phenocrysts, Framboidal; percent; present or absent; size	Assessment of acidification potential and salinity increases.	Petrographic analysis; X-ray diffraction, electron microscopy (Arora and others, 1978).
Clay mineralogy	Clay mineral type; percent	Evaluate moisture and fertility relationships, strata.	ASA Monograph No. 9, Part 1 Ch. 44, 45, 49; p. 568-601, 611-696.
Sand mineralogy	Mineral, matrix, and cement percentages	Evaluate weatherability, strata, and fertility.	ASA Monograph No. 9, Part 1 (1965), p. 604-630.

[1]Reference citations given in literature citation section.

[2]Dispersion of overburden samples by ultrasonic frequency is recommend

[3]Reagents oxydize reduced sulfides and give high results.

[4]Water soluble sulfate and gypsum should be deducted from total sulfur.

A screening procedure is given for some de-erminations such as potentially toxic elements nd pyrite along with a more quantitative proce-lure where such acceptable procedures are vailable.

ample Selection Guidelines for Chemical, lineralogical, Textural and Physical Analyses

Criteria and guidelines for selecting and andling soil samples for laboratory characteri-ation are given in table 4. Approaches for sam-ling geologic overburden materials are discussed the drilling section. The data requirements nd sample selection criteria for geologic over-urden might be greatly simplified if soils were haracterized as to suitability and adequacy prior o overburden characterization. If it were known hat adequate amounts of "topsoil" materials ere available for reclamation, then fertility and ther analyses specifically needed for plant owth characterization could be eliminated. nly those analyses related to environmental azards of overburden and to mining operations ould then be needed. Moreover, the total num-r of time-consuming analyses could be reduced nsiderably by a general screening approach for ientifying such hazards as pyrite and some po-ntially toxic elements. A rapid qualitative emical screening procedure can be used to timate the relative amounts of pyrite present i overburden strata, for example. A more quan-tative procedure can then be used on samples ntaining detectable amounts of pyrite. Also, a ge number of elements can be determined si-ultaneously on one sample by total elemental alyses with emission spectroscopy. These ana-es can serve as a screening method for poten-tilly toxic elements. Samples with high or mar-g al total elemental concentrations can then be sjected to more specific quantitative analyses f salinity.

If "topsoil" materials were insufficient or re unsuitable as plant growth media, then orburden could be more thoroughly analyzed t assess the possibility of overburden being more stable as plant growth media than "topsoil." In general, all samples should be representative o the intervals to be sampled (equal amounts of th interval thoroughly mixed) so that the quan-ti tive significance of the analyses can be assessed. Also, it is recommended that enough extra sample be retained so that analyses can be repeated if necessary or for further analysis in case questions arise in the future.

GROUND WATER AND SURFACE WATER CHEMISTRY

The use of proper sampling procedures for ground and surface water is imperative in order to ensure accurate water quality information. The field investigator must be sure that his sample is representative of the water body under investigation for decisions based upon water quality data are vitally dependent upon sample validity. It has been suggested that improper sampling location may yield the greatest source of error in the entire water quality data acquisition process (Hem 1970). The following is a brief summary of proper sampling procedures; for additional information see Hem (1970) and Rainwater and Thatcher (1960).

Surface Water Sampling

The following criteria should be considered when establishing a surface water sampling network (adapted from Rainwater and Thatcher 1960):

1. The water is completely mixed and of uniform composition.

2. Each sampling location fits into a comprehensive network for evaluating chemical composition throughout the study area.

3. The data gained from the sampling network can be correlated with information derived from other sampling programs in the area.

4. The sampling location is such that estimates can be made of the amount of total dissolved material discharges from the area.

5. Location of the sampling point is at a transition from the surface outcrop of one geologic formation to another.

6. Location can be used to monitor both pre and postdevelopment water quality.

7. Locations provide information about the water quality upstream and downstream from the development area.

Ground Water Sampling

Water samples taken from idle, nonpumping wells are usually not representative of the ground water chemistry. Well water above the screened interval is isolated from the aquifer and tends to be stratified and stagnant. Furthermore, this water may contain foreign material from the surface and include chemical compounds derived from the well casing and drilling fluids.

To avoid the collection of nonrepresentative, stagnant water samples, each well should be thoroughly flushed out prior to sampling. For high capacity wells, 3 to 5 times the volume of water contained in the casing should be evacuated to obtain a representative sample. Low capacity wells should be pumped completely dry and allowed to recover; if recovery is rapid, the well should be completely evacuated 2 or 3 times prior to sampling. To ensure complete removal of the stagnant water, the pump screens or discharge line inlet should be placed as near to the well screen as possible.

The following equipment is suitable for the collection of ground water samples: (1) bailers, (2) surface pumps (peristaltic, centrifugal, vacuum), (3) submersible pumps, and (4) air lift equipment.

Care must be taken when using any of these devices for sampling purposes; improper handling and poor sanitation will compromise the worth of the water sample, possibly leading to incorrect management decisions. Specifically, bailers should be used only when it is possible to completely dry out the well by bailing, otherwise the sample is unreliable. Pumps and air lift equipment are probably the best means of collecting ground water samples. Unfortunately, all these devices tend to aerate the water sample which may affect the concentration of heavy metal ions and other constituents. Rapid sample preservation will minimize the aeration effects.

The following data should be collected at each surface and ground water sampling station.

Data	Surface water	Groun water
Name of water body	X	X
Site location	X	X
Point of collection (pump discharge, etc.)	X	X
Method of collection	X	X
Time and date	X	X
Gage height or discharge	X	X
Temperature	X	X
Collector's name	X	X
Well number		X
Well depth		X
Well diameter		X
Screened interval		X
Static water level		X
Filed conditions	X	X

Sampling Frequency

Water quality sampling frequency sho be such that no important or significant chan in water quality go unnoticed between sampl times (Rainwater and Thatcher 1960). In gene sampling frequency should be proportional the variability of the water chemistry; stati with high water quality variability should sampled more frequently than stations with c sistent water quality. Obviously, the hydrolo must seek a compromise between the accur and detail desired in the water quality rec and available funding. In most cases, quart or biannual sampling intervals are sufficient confined ground water quality studies. Unc fined ground water may require more frequ sampling. Higher sampling frequencies are usu required for most surface water stations du the greater water quality fluctuations brou about by the variability in discharge and m orological effects.

In some cases it is possible to reduce la ratory analysis costs by measuring a few "ind tor constituents" at frequent intervals while forming more expensive complete analyses c when the indicators suggest significant w

juality changes. Possible indicator constituents nclude temperature, electrical conductivity, pH, hardness, and alkalinity; these measurements should be done in the field.

Sample Preservation and Constituent Analyses

Sample preservation should never be regarded as absolute, as it is impossible to achieve complete stability for every constituent to be analyzed. Preservation techniques serve only to retard the chemical and biological changes that occur in the sample container. For this reason, it is essential that water samples be preserved as soon as they are collected and analyzed as soon as possible.

Laboratory-grade glass or plastic containers are suitable for the storage of most natural waters. Care should be taken that each sample bottle is absolutely clean. To ensure cleanliness each container should be treated as follows: Wash each bottle thoroughly with detergent, rinse with tap water followed by a nitric acid rinse, rinse again with tap water, and finally, rinse with deionized water. Following this procedure each bottle should be sealed until needed. In the field, each bottle should be rinsed thoroughly with the sample, then filled completely leaving as little entrapped air as possible.

The two most commonly used field preservation procedures are refrigeration and filter/acidification. For the refrigeration method the sample is simply collected in the sample bottle then immediately cooled to below 4° C using ice or other means. The advantages with this method are that little sampling equipment or chemicals are needed and the procedure is simple. This method may not be practical, however, when sampling warm water or during hot days because large quantities of ice are required to ensure adequate cooling and preservation. If a constant temperature below 4° C cannot be maintained, then the filter/acidification procedure must be used. Filter/acidification requires the following equipment: prefilter papers, 0.45 μ filters, filter chamber (USGS or Skogstadt type), nitric acid, zero-impurities grade nitrogen gas (required only when minor elements or heavy metals are to be analyzed).

A portion of the water sample is placed in the pressurized filter chamber and forced through the filters at pressures below 15 psi. The filtered fraction is then stored in two separate portions; a 1 liter portion that has been filtered and then acidified with nitric acid to a pH of 2.0 and a 250 ml portion that has been filtered only. Also, 250 ml of raw water should be sampled in addition to the filtered portion. Each sample bottle should be labeled according to its field treatment; the nitric acid should be added directly to the 1 liter portion in the sample bottle. All water samples should be kept as cool as possible and out of direct sunlight regardless of the preservation method.

Due to preservation difficulties, some water quality parameters must be analyzed in the field in order to obtain accurate data. Analyses that must be done in the field include: temperature, electrical conductivity, pH, alkalinity, dissolved oxygen, carbonate, and bicarbonate.

The following parameters should be analyzed in connection with premining, mining, and postmining water quality monitoring programs (from Wyoming Department of Environmental Quality, Division of Land Quality Guidelines #4):

pH	arsenic	mercury
temperature	cadmium	nickel
total dissolved solids	calcium	nitrate (or N)
electrical conductivity	chromium	phosphorus
alkalinity	copper	potassium
hardness	flouride	selenium
carbonate	iron	sodium
bicarbonate	lead	sulfate
aluminum	magnesium	zinc
ammonia	manganese	

For uranium mines add: redox potential, molybdenum, vanadium, uranium, and radium.

For surface water add: dissolved oxygen, and total suspended solids.

The significance of each of the above constituents is discussed in United States Environmental Protection Agency (1976). It may not be necessary to analyze for all of the above in every case, of course. The composition and levels of constituents found in initial sampling should be used as a guide for analysis of subsequent sampling.

GREENHOUSE STUDIES AND PLANT TISSUE ANALYSES

Perhaps one of the greatest problems facing both laboratories providing data and planners and land managers receiving these data is "interpreting" the meaning of many of the soil chemical and biological assay data that is being required for assessing the suitability of soil and/or geologic overburden as plant growth media. Public pressure has forced them into performing tests before they were ready with data needed to interpret these tests.

Thus, a serious gap exists for which calibration data is needed. This information can be supplied in several ways — through laboratory and/or greenhouse studies which give only partial answers; or through field studies which require long periods of time and are subject to loss because of weather, diseases, etc., and the results of which are not always easily transferred from one site to another; or by a combined greenhouse, laboratory, and field experimental program. The latter approach is perhaps the most economical and efficient in terms of time and reliability.

The purpose of this section is not to infer that greenhouse and associated soil and plant diagnostic studies should always and everywhere be considered. Rather, the information is provided to encourage mining companies and/or agencies to develop research programs that are needed to fill critical data gaps.

The usefulness of greenhouse and plant tissue analyses studies has long been demonstrated in soil test-plant nutrient correlation studies on agronomic crops. And it seems fair to say that this approach is compatible as a basis for studying these same relationships associated with mined-land reclamation. Differences between them are probably more by degree than actual.

When one considers the multitude of conditions that exist in terms of soils, crops, or vegetation types; climatic conditions; and management alternatives associated with areas in which surface mining is taking place, it becomes apparent that field trials cannot, in a practical sense, be carried out in sufficient time to provide t calibration data needed. Greenhouse and ass ciated soil and plant diagnostic techniques shou be considered as a viable screening mechani for identifying the nature and extent of potent soil-plant nutrient deficiencies and/or toxicit that might be associated with the soil-plant s tems being managed. Data furnished from th types of studies can serve as a useful tool in p mining evaluation of soil and/or overburden m terials, as well as being a reliable basis for det mining the variables that should be included field experiments.

Some considerations that should be kept mind in developing these types of studies are:

1. Sample selection and collection. Ma rials should be sampled on the basis of what f tors are to be studied.

2. Amount of material. This will vary pending on the extensiveness of the study volved. The experimental design should inclu a minimum of 2 replications and pot size sho be 1/2 to 1 kg. Thus, if an experiment requi 10 treatments and 2 replications (20 pots) amount of material required would be a m mum of 10 to 20 kg. The amount of mate collected should also consider laboratory nee

3. Type of crop.

4. Type of soil and/or plant analyses be performed.

5. Sample preparation. Material sho have a particular size where most of the mate falls into the < 2 mm size range. If coarse or c solidated materials are ground, it is desirabl avoid crushing too fine.

Note: Criticism has been made concerr grinding materials for greenho study. It must be recognized, h ever, that the part of the soil m rial that influences plant gro most significantly is the < 2 fraction material.

6. Experiment design. Should be de oped jointly by the researcher and those desi the research to be performed.

ELD REVEGETATION AND 'ABILIZATION STUDIES

It would appear that field experiments to aluate existing site conditions may be useful. r example, sampling of plants as well as soil iterials for laboratory analyses would provide excellent means for evaluating the soil-plant trient deficiency and/or toxicity potentials it currently exist. In addition, treatment of sting soil-plant systems with fertilizer and/or l amendments can help to indicate the nature d degree of response to treatments that may proposed for reclaimed areas. In effect, these es of studies would provide baseline data for nditions as they currently exist, which in turn serve as a basis for evaluating soil-plant relanships that might occur after land disturbance mining.

As in the case of greenhouse and plant anas studies, the foregoing discussion does not r that field experimentation is always and ywhere needed for obtaining data in develng a reclamation plan. Again, this section of report is provided to encourage, where pose, the implementation of field investigations provide needed and useful information.

In addition, a program should be developed ddress two distinct activities: (1) laboratory greenhouse research to provide basic correla and calibration data, and (2) field experitation to provide a mechanism for transfer laboratory and greenhouse studies into inretations that apply to the environments re the reclamation activities are taking place.

Field experimentation needs relative to lems associated with reclamation in the ern United States, as reported by various reahers, include erosion, species adaptability, ity needs, potential plant and animal tox and salinity and sodium problems. Appen contains some useful references concerning factors and should be reviewed so as to fit from previous research efforts.

The main purpose of this section is to pro a summary of "principles of field experi." Basically, the principles of field experiation are as follows:

Describing the Component Parts of the System which will Affect the Experiment

These are:

1. Communities of plants being grown or being proposed. Choice of plants to be used could come from an assessment of current soil-vegetation relationships.

2. Soil characteristics.

3. Climatic conditions.

4. Associated biological entities — weeds, insects, diseases, and animals that might destroy plots.

5. Cultural and management practice alternatives.

Selection of Experimental Sites

Criteria are:

1. *Uniformity.* — Sites must be selected where uncontrolled variables are the same over the entire experimental site, (depth of soil, kind of topsoil and subsoil material, etc). Selecting the experimental site for uniformity of uncontrolled variables will minimize experimental error and the number of replications needed.

2. *Number of replications.* — Enough field studies have been conducted to suggest that a minimum of 4 replications per treatment are needed to minimize experimental error. Also, it is important to remember that uniformity within a plot is essential, particularly when there is variability within the entire experimental site.

Variables to be Studied

We should identify and define the kind and level of uncontrolled variables as well as the controlled variables. In other words, the controlled variables might be a study of the effect of various mulches in controlling erosion. Soil fertility may be an uncontrolled variable. The fertility status of the soil should be determined because it may be a limiting factor that affects response to the

controlled variables. In this case, it may be desirable to apply a standard rate of fertilizer over the entire study area to eliminate this variable as a limiting factor.

Plot Design

Selection of a plot design is critical because different plot design techniques allow for greater or lesser precision in controlling experimental error, either by accommodating or not accommodating site variability and/or combinations of treatments. Randomized complete block and split-plot designs are most commonly used. A useful reference for determining a plot design suited for the type of experiments proposed is LeClerg and others 1962.

In addition, plot design should consider the data analyses portion of the research. The principle types of field experiments now desired are those that will provide multiple regression analyses which relate responses to different vari
and to their interactions. Field experim
should be designed for this purpose.

Site Protection

We recognize that the establishment of
experiments often attract animals of va
kinds, (gophers, rabbits, mice, deer, ante
elk, etc). Because field experiments are cost
establish, a site protection plan — na
fencing — is essential. The possibility of
such as grasshoppers invading the site also
be considered.

In summary, field experimentation,
ported by laboratory and greenhouse stud
the primary mechanism for establishing c
plant nutrient deficiency and/or toxicity cri
The "state of the art" is inadequate for ass
many of the "data interpretive" questions
asked.

DATA EVALUATION AND APPLICATION

Geologic Overburden

From the standpoint of mine land reclama-
n the following questions should be addressed
mining and reclamation plans and environ-
ntal reports: What are the nature and magni-
de of both the beneficial and the adverse af-
ts resulting from the proposed surface mining
ivity? What actions must be taken to mitigate
minimize any possible environmental damage
verse effects)?

Specific adverse effects that might need ad-
ssing in mining, reclamation and environ-
ntal reports include:

1. Handling of overburden rock units that
highly acidic, saline, or sodic and units that
tain high levels of phytotoxicants (particu-
y heavy metals).

2. Constitution of a suitable soil or sub-
material from overburden rock units should
ing operations result in excessive disruption
narginal surface soils.

3. Final contouring of surface and rees-
ishment of surface drainage after backfilling
rations are completed to minimize subsequent
ion and to optimize surface runoff from the
ed area (Keefer and Hadley 1976).

The geologic data base that should be avail-
to aid in answering these questions and in
gnizing and addressing these adverse effects
udes:

1. Maps of the exploration area showing
surface topography and the location of bore-
s, pits, roads, etc.

2. A detailed geologic map showing the types of surface materials, location of potential borrow deposits, and geologic hazards.

3. Lithologic and geophysical logs of boreholes. Photographs of cores and lists of all retained cores and/or cuttings, and methods used for backfilling all boreholes and pits.

4. Geologic cross-sections showing soil and rock types and rock structure within the proposed mine area.

5. Isopach maps of the topsoil, the overburden and interburden, and the host rock or coal seam. Ratios of overburden to host rock or coal seam thicknesses.

6. Structural contour maps showing the subsurface elevations of the floor of the host rock or coal seam and the subsurface elevations of major rock units that contain high levels of toxic or undesirable materials.

7. Records of all geochemical, mineralogical, and textural analyses.

8. A narrative summary of the conditions of the exploration site to include: regional geology and seismicity; surface conditions and topography; physical, mineralogical, and geochemical characteristics of the overburden and interburden material; nature and extent of toxic materials present in the overburden; and geologic hazards.

It is readily apparent from a review of the literature that there is a lack of information concerning the physical and chemical characteristics of geologic overburden materials in many potential surface mine areas in the Western United

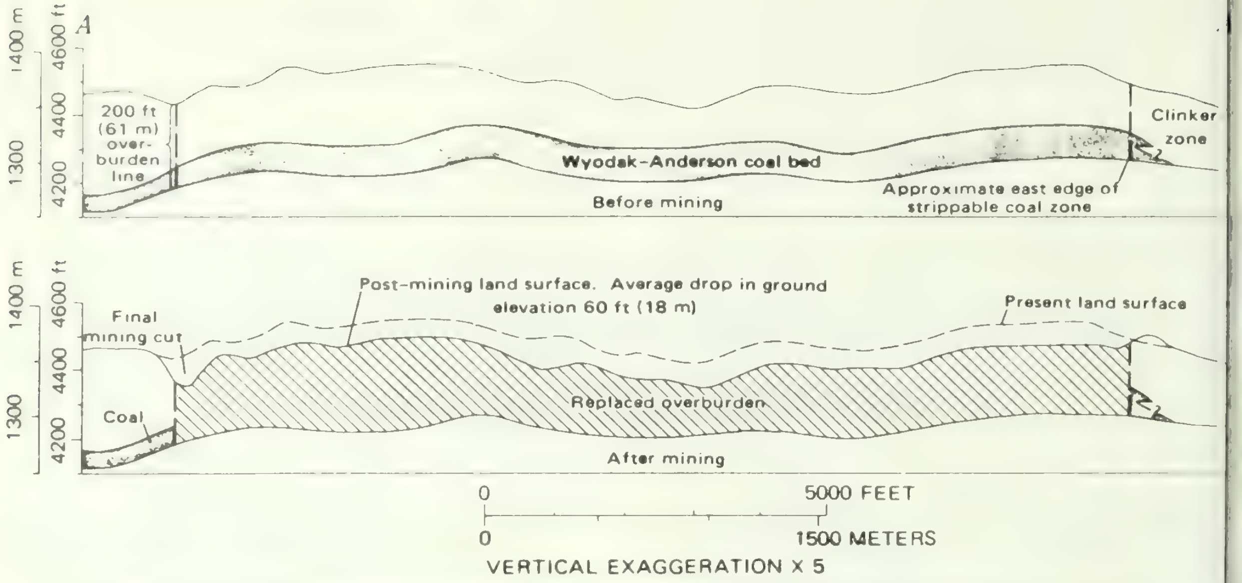


Figure 13. Cross-section showing potential changes in topography resulting from surface mining in the Gillette area, Wyoming. Lower section is based on assumption that overburden is replaced on a cut-by-cut basis with 200 ft wide (60-m-wide) cuts, spoils are smoothly graded, high walls, are graded to a 3:1 slopes, and overburden expands 20 percent. (from Keefer and Hadley 1976, fig. 14, p. 19)

States such as the Fort Union region in North Dakota. Most of the overburden in this area, as well as in other areas of the Western United States, appears to be saline and sodic shales and claystones which create severe problems in rehabilitation. Scoria, sandstone, and gravel, while more desirable for rehabilitation, are also more scarce. Some of the shales and claystones might be less saline, and if so, more easily rehabilitated. An inventory of these more preferred substrata is certainly desirable and warranted (Thorne Ecological Institute 1975).

In some surface mine areas of the Western United States these types of inventories are presently under way by State and Federal agencies. One particular area that has received considerable attention is west central North Dakota (Moran and others 1978). Another such area is the Gillette area in Wyoming. The U.S. Geological Survey is gathering data on the topography, landforms, geology, coal reserves, geochemistry, surface water, erosion and sediment yield, and groundwater to ascertain the potential effects of surface mining of coal (Keefer and Hadley 1976).

One inevitable effect of surface mining is the alteration of the surface topography as a result of surface mining operations. This altera depends on factors such as depth and thick of the coal being mined and the manne which the overburden is being replaced in mined-out pits. A cross-section showing the potential changes in topography in the Gill area as a result of surface mining of coal is g in fig. 13. Knowledge of the postmine lands is especially important in areas where the s pable coal is thick in comparison to the over den material. Such reconstructions are essei to determining the potential distribution of face drainage and predicting changes in ero and sediment yield patterns. Because of thickness of the coal in this area, the ground face will be lowered considerably (fig. 13). result, extensive closed depressions may created and gullying along stream course stream from high walls and increased ero and sediment yield may result if proper recl tion procedures are not followed.

Potential environmental problems suc those found in the North Dakota and Gil areas can only be recognized if a sufficient base from overburden and hydrology st exists. Solution to some potential environm

problems must be based on a regional as well as a site-by-site basis.

Soil and Overburden

FIELD INVENTORY DATA APPLICATION

The field inventory maps and accompanying descriptive information will be directed toward answering the following basic question: How much soil material is available that is suitable as plant growth media and what is the distribution of these materials on the site?

The field inventory data base should include the following information for answering the above question:

1. Adequate soil profile descriptions so that topsoil and subsoil isopach maps can be developed to calculate the amount of material.

2. Soil map at a scale sufficient to portray the extent and distribution of the different kinds of soils which occur.

3. Adequate soil mapping unit description to determine the relative homogeneity of soils within a mapping unit and to provide adequate information for making land capability interpretations.

4. Interpretive classifications should be made for each soil mapping unit with regard to land capability classification, important and unique farmlands, range-site classification, erosion susceptibility, and other soil and/or land classification interpretations that might be useful in developing a reclamation plan.

Most of the interpretive classifications can be developed very easily if the field data are collected using the procedures outlined in this report and the interpretation guidelines, which are available from agencies such as the Soil Conservation Service, USDA; Bureau of Reclamation, USDI; Forest Service, USDA; and Bureau of Land Management, U.S. Department of the Interior.

LABORATORY DATA APPLICATION

The major problem facing land planners, relative to use of laboratory data, is identifying data needs and interpreting the data once obtained. The diversity of management goals, controlling specifications, variability in physical and plant system environments, and lack of interpretive correlation data makes this task somewhat difficult. Further, the complexity of these interrelated factors renders impractical any attempt to develop or apply uniform criteria. In addition, definable and applicable criteria are more reliable for dealing with some factors as compared to others.

This section is an attempt to present the "state of the art" in interpreting and applying laboratory data in mined-land reclamation and to provide a basis for knowing what to look for in differentiating what is important and what is not in relation to individual projects.

This section is written to present information that can be useful for evaluating and applying laboratory data to the following concerns: (1) soil fertility relationships, (2) soil salinity and/or sodium relationships, (3) soil textural relationships, (4) mineralogical relationships, (5) trace element deficiency and toxicity relationships, (6) soil erosion relationships, and (7) developing a soil and geologic overburden laboratory characterization program.

Use has been made in this section of many sources of unpublished as well as published information.

Soil Fertility Relationships

The uptake of nutrients by plants is one obvious criterion for assessing their availability. No two species of plants growing on the same soil, however, take up the same quantity of the various nutrients. These variations in uptake are the result of such things as pH of the soil, moisture status, overall fertility status, nature of the plant, and content in the soil of the nutrients.

The above interrelationships have been resolved (at least to a satisfactory degree) for many soil-plant systems through soil test corre-

lation research programs. Most of these investigations have, however, been carried out for agronomic crops under soil moisture regimes quite different from those in which surface mining is taking place in the Western United States. Although agronomic and/or introduced forage crops will be used in some areas in reclamation for which some existing soil test correlation data will be applicable, native vegetation, as well as drier soil moisture regimes, will be the more common soil-plant system for which fertility assessments are made.

Thus, the "state of the art" for evaluating potential soil fertility needs associated with most reclamation efforts is based primarily on judgment.

Data shown in table 15 identifies the soil test-fertilizer recommendation criteria currently being used by the Colorado State University Soil Testing Laboratory. The fertility interpretations provided are thought to be those which most closely approach mined-land reclamation interpretive needs. It must be remembered, however, that these relationships are based on correlation data for a given soil chemical extraction method and for specific crops. (Soil test methods are indicated in table 15.) The purpose for providing this information is not to suggest that the fertilizer treatments recommended be universally applied. This would be undesirable because the recommendations do not have regional application because of crop, climatic, and soil differences. Rather, the information is provided to serve as a first approximation in attempting to identify and/or isolate potential fertility problems associated with a mined-land reclamation effort, recognizing that what might be considered a low soil P level for one type of plant may not be low for another type of plant and/or soil moisture regime.

N and P are recognized as being the most potentially limiting plant nutrients in soils of reclaimed areas in the arid and semiarid West. The degree of deficiency, however, varies greatly due to soil properties, plant type, prevailing climatic conditions, etc.

Although there are little data available, the following is a summary of the present "state of the art" for evaluating the status of several other nutrients in addition to those listed in table 15 and/or discussed in the section which follows:

Sulfur. — Deficiency very unlikely to occur but usually is potentially limiting in very coarse, well-drained, low organic matter soils.

Calcium. — Generally present in sufficient quantities; however, may be important from the standpoint of plant nutrition because of the ratio of Ca to Mg. When Mg exceeds Ca on an equivalent basis, plant yields may be influenced. High Mg to Ca ratios have been found for a number of geologic overburden materials. Specific criteria for evaluating this relationship are not well developed.

Boron. — Deficiency, if it occurs, is probably restricted to isolated situations. Toxicities are likely to be more common than deficiencies.

Molybdenum. — Because of the alkaline nature of most soils found in arid and semi-arid regions, deficiency of this element is unlikely to occur.

In summary, research is being carried out in various parts of the Western United States by State, Federal, and private groups in an attempt to develop interpretive data for evaluating nutrient deficiencies. Thus, soil fertility evaluations can best be made through contact with persons having ongoing research programs.

Soil Salinity and Sodium Relationships

Excessive salinity and exchangeable sodium in soil and geologic overburden are found to be problems hindering revegetation of strip-mines in many areas in the arid and semiarid western regions. General guidelines for evaluating suitability of topsoil (A horizon), subsoil (B and C horizons) and geologic overburden for revegetation of regraded mined lands under nonirrigated conditions are given in table 16. Since irrigation water and soil amendments can ameliorate salt and sodium conditions and present a large array of interpretive problems, the guidelines are limited to nonirrigated conditions except where salt and sodium reach "undesirable" levels. Similarly plants have a wide range in salt tolerance characteristics which cannot even begin to be covered

Small grains

(1) NO_3–N soil test p/m	Soil organic matter – % 0-1.0 Fertilizer N lb/acre	1.1–2.0	>2.0	(2) Phosphorus (P) soil test p/m	Fertilizer phosphorus lb/acre P_2O_5	(3) Postassium (K) soil test p/m	Fertilizer potassium lb/acre K_2O
0-6	50	40	30	0-7 low	40	0-60 low	30
7-12	30	20	10*	8-14 medium	20	>60 high	0
13-18	10*	0	0	14 high	0		
19-24	0	0	0				
>24							

10 lb N is recommended only when phosphorus and/or potassium is also required.

Native and improved range grasses

NO_3–N soil test p/m	Soil organic matter – % 0-1.0 Fertilizer N lb/acre	1.1–2.0	>2.0	Phosphorus (P) soil test p/m	Fertilizer phosphorus lb/acre P_2O_5	Postassium (K) soil test p/m	Fertilizer potassium lb/acre K_2O
0-6	40	20	0	0-7 low	30	0-60 low	30
7-12	20	0	0	>7 high	0	>60 high	0
12	0	0	0				

(1) Phenoldisulfonic acid method
(2) Sodium Bicarbonate Extractable P levels
(3) Ammonium Acetate Extractable

The above soil test values can be interpreted only for soils tested by the respective methods listed.

Remarks

Experience and test results to date indicate that N and P are the elements most likely to be deficient in soils on mined land reclaimed areas. However, responses to fertilizers which are applied to correct these deficiencies are not always obtained because other factors such as soil moisture may be more limiting than these nutrients. The likelihood of a response to added K even at low K soil test values is probably minimal except possibly on very sandy soils.

The authors of this manual know of no available data which can be used to evaluate other nutrient deficiencies.

Below are listed critical levels at which Fe, Mn, Cu, and Zn are considered to be potentially deficient for those agronomic crops which are sensitive to deficiency of these elements and in many cases for those crops grown under irrigated conditions. They cannot and should not be interpreted as being critical for most of the plants grown on most soils/spoils and soil moisture regimes in the Western United States. However, if the levels fall much below those identified below, further evaluation may be necessary.

Element	DTPA extractable p/m (critical level)
Zn	<0.25
Fe	<2.5
Mn	<1.0
Cu	<0.2

Table 16. – Suitability of topsoil, subsoil, and overburden for revegetation of regraded surface mines under non-irrigated conditions in arid and semiarid regions

Factor	Material	Highly suitable (excellent to good)	Suitable (fair)	Undesirable except with amelioration (poor)	Amelioration
$EC_{se} \times 10^3$ mmhos/cm	Topsoil (A-horizon)	<2	2-4[1]	>4[1]	Leaching to reduce to <4
ESP	Topsoil (A-horizon)	<5	5-10	>10	Amendment to reduce[2] ESP to <10
$EC_{se} \times 10^3$ mmhos/cm	Subsoil (B & C horizons)[3]	<4	4-8	8	Leaching to reduce to <8
ESP	Subsoil (B & C horizons)	<10	10-15	15-30[4]	Amendment to reduce[2] ESP to <15
ESP	Subsoil (B & C horizons) 2:1 swelling clay content >65% of <2 μ fraction	<5	5-10	10-15	Amendment to reduce[2] ESP to <10
$EC_{se} \times 10^3$ mmhos/cm	Overburden (B & C horizon contact material)	<4	4-8	>8[1]	Leaching
ESP	Overburden (B & C horizon contact material)	<10	10-15	15-30[4]	Amendment to reduce[2] ESP to <15
$EC_{se} \times 10^3$ and ESP	Overburden as a substitute for topsoil or subsoil (B & C horizon)	Same EC & ESP criteria as topsoil and subsoil			

[1] Changes to suitable with supplementary irrigation water having $EC \times 10^6$ <1000 μ mhos/cm and SAR <5 or annual precipitation >18 inches.

[2] Amendment alternatives: native gypsum, commercial gypsum, commercial low-B $CaCl_2$.

[3] Minimum thickness of overlying A not <6 inches (15 cm).

[4] 2:1 swelling clay content 65% of <2μ fraction — reduce to topsoil value if > 65%.

dequately within the purpose and intent of hese guidelines. The guidelines for salinity were pproached on the basis of difficulty in obtaining plant stands on saline soils under nonirrigated onditions. Most plant seeds will germinate under quite saline soil conditions but a great many will fail to emerge and, if emergence takes place, many die during the seedling stage, espeially if drought conditions exist simultaneously.

The excellent to good suitability rating for oil salinity and sodium are those levels that hould result in little or no difficulty in estabishing stands of plants usually used for revegeation and would qualify for "prime-land" category, with respect to salinity and sodium. Also, ittle or no decrease in plant production after tand establishment would be expected as a reult of soil salinity or exchangeable sodium. Lower levels of salt and sodium are recommended or A horizon topsoil placed on the surface. Higher salt levels can be tolerated in the lower depth because plants usually increase in salt tolrance after establishment. Lower exchangeable odium levels are recommended for A horizon opsoil or topsoil substitute because the soil surace is critical for maintenance of good wateroil-plant relationships. It is necessary to mainain an acceptable infiltration rate to prevent exessive runoff and erosion especially on steep lopes, a 10 percent Exchangeable Sodium Perentage (ESP) probably will not be significant in educing infiltration rates especially on sandyextured soils. Some downward movement of xchangeable sodium can be expected, however, ven in arid areas. Downward movement of exhangeable sodium can affect the permeability f subsoil layers. Also, translocation of clay can e initiated at relatively low Exchangeable Soium Percentage (ESP) levels with rainwater. ranslocation of clay would reduce the moisture etention of the surface soil and reduce the ermeability of lower depths. Loss of clay from he surface layer could result in an increased ind-erosion susceptibility. Thus, the long-term ffects of ESP may be more important than imediate effects.

The "fair" suitability rating for salinity evels is in the range where difficulties in establishing a stand under nonirrigated conditions and educed plant production might be expected, esecially if agronomic species were grown. The "fair" rating for exchangeable sodium would be in the range where some adverse effects on physical properties might be expected, especially on finer-texture materials. Expected adverse effects might be reduced infiltration and permeability, reduced aggregation, and increased water or wind erosion. Migration of salt or sodium, either upward by capillarity or downward by leaching, is possible also.

The "undesirable" rating does not necessarily mean that the soil or overburden could not be used. It may be that the material represents the "best available" in some cases. It does mean, however, that it would probably be necessary to develop water for irrigation and to use amelioration procedures to decrease salt and/or exchangeable sodium to levels that would insure successful revegetation. An arbitrary upper limit of 30 percent exchangeable sodium was imposed for economic considerations; the application of amendments and leaching to dissolve the amendments is a costly and time-consuming process. For example, about 1.7 tons of gypsum (100 percent purity) per acre are necessary to reduce exchangeable sodium by 1 meq/100 g in a 1-ft depth of soil. On the average, it will require that about a 1 to 1.4 ft depth of water be applied per acre to dissolve the 1.7 tons of gypsum so that calcium can replace sodium. An amendment, such as calcium chloride, is much more soluble but it is also much more expensive than gypsum. The water requirement for leaching of soil salts alone is usually much lower than for dissolving an amendment.

As with other aspects of strip-mine reclamation, considerable site-specific judgment needs to be exercised.

Soil and Geological Overburden Textural Relationships

Texture is an important soil property to evaluate in surface mine reclamation planning. In general, texture should not be examined from the standpoint of sand, silt, and clay distribution, per se, but the evaluation should be based upon several important properties that are closely related to texture. A list of factors affected by or related to texture are given in table 17. A generalized rating for each property is given for

Table 17. – Generalized rating of factors probably needing assessment in surface mine reclamation as affected by texture of soil or overburden

Factors Affected by Texture	s[1]	ls	lfs	sl	fsl	vfsl	l	scl	sicl	cl	sc	sic	c
1. Water Infiltration	rapid	rapid	rapid	mod. rapid	mod rapid	mod	mod.	mod. slow	mod. slow	mod slow	slow	slow	very slow
2. Moisture Retention	very low	very low	very low	low	low	mod.	mod	mod. high	mod high	mod high	high	high	very high
3. Potential for Water Stable Aggregate Formation from Dispersed Material	very low	very low	low	low	low	low	mod.	mod.	low	high	high	mod	high
4. Sodium Dispersion Susceptibility	very low	very low	low	low	low	mod	mod.	mod	high	high	high	very high	very high
5. Tendency for Crust Formation on Soil Surface	very low	very low	very low	low	low	mod.	mod.	mod.	high	high	high	very high	very high
6. Wind Erosion Susceptibility	high[2]	mod.[2] high	mod. high	mod. low	mod.	mod. high	low	mod. low	low	low	mod low	low	low
7. Water Erosion Susceptibility	very low	very low	low	low	low	mod.	mod.	mod.	high	high	high	very high	very high
8. Aeration	very good	very good	good	good	good	good	good	good	fair	fair	fair	poor	poor
9. Inherent Fertility	low	low	low	mod.	mod.	mod.	mod.	high	high	high	very high	very high	very high
10. Fertilizer Retention	low	low	low	mod.	mod	mod.	mod.	high	high	high	very high	very high	very high

[1] s-sand, ls-loamy sand, lfs-loamy fine sand, sl-sandy loam, fsl-fine sandy loam, vfsl-very fine sandy loam, l-loam, scl-sandy clay loam, sicl-silty clay loam, cl-clay, sc-sandy clay, sic-silty clay, c-clay.

[2] very fine, fine and medium sands and dune sand.

ach textural class. Textures most suitable or menable to reclamation and revegetation gen-rally fall between the sandy loam to clay loam extures. However, a primary consideration hould also be maintenance of the integrity of ne soil profile developed under natural condi-ons, in so far as possible. Thus, criteria for de-ermination of suitability with respect to texture largely "site-specific" and rigid guidelines can-ot easily be made. It is suggested that an at-empt be made to rank order properties of dif-erent materials that are available according to elative importance for a specific climatic and opographical setting and assign a score to each extural class available as topsoil, subsoil, or verburden to arrive at a total quantitative score or each material available. The material with ne highest quantitative score would be consid-ered as most suitable at that specific site. Prop-rties to evaluate include infiltration, permeabil-y, structures, water holding capacity, stoniness, lt and exchangeable sodium, surface crusting isceptibility, wind and water erosion suscepti-lity, fertility, and possibly others. Salt and ex-hangeable sodium ratings and erosion equations e discussed in another section. The amount of fferent materials available for regrading or soil construction is also an important factor to be nsidered. Qualitative suitability ratings of veral factors were used by McKall and Associ-es (1978) to obtain an overall rating of soil itability for stripmine rehabilitation.

The "slaking test" (table 14) is used to aluate consolidated overburden as a potential il substitute material. If 65 percent or more of e consolidated core sample passes through a mm sieve opening after being wet under vac-m and then shaken for 15 minutes in a hori-ntal shaker, it can be considered that the strata ll weather rapidly and be suitable as plant owth media. The infiltration and/or permeabil-y of soil and overburden materials after distur-nce are difficult to predict except on a general sis of texture or to measure after regrading. It expected that infiltration and permeability of il materials will be higher than measured values the field after regrading but will gradually de-ease until they approach the value obtained fore disturbance. Laboratory measurements of ydraulic conductivity" (table 14) probably present the best approach for screening different textured overburden materials. The "shrink-swell" test (table 14) should provide additional information for evaluating expected permeability changes under saturated conditions.

The following general rules can be applied in relation to other texturally related properties. Field capacity gravimetric moisture content can be closely estimated as: 1/2 paste saturation, percent. Volumetric field capacity can be estimated as: gravimetric moisture, percent times bulk density. Wilting point can be estimated as: 1/4 paste saturation, percent. The difference between field capacity moisture content and wilting point can be used as an estimate of "plant available water".

Better plant stands, more vigorous growth, and higher production of plant material are normally obtained on A horizon topsoil if it is not mixed with subsoil layers or overburden. Germination and emergence of seedlings are usually better on a coarse-textured A horizon than on a structureless fine-textured A horizon, unless moisture is very limiting. Fine-textured materials have a greater tendency to form surface crusts, which decrease the emergence of seedlings.

In general, a fine-textured A horizon should be stripped and stockpiled separately from finer-textured textural B and/or C horizons even though the A horizon is relatively thin. Mixing a textural B horizon (B_2t) with a fine-textured A horizon, for example a clay loam, is apt to markedly decrease water infiltration and increase erosion. Mixing a textural B horizon with a greater or equal amount of sandy A horizon usually will not decrease infiltration to seriously low rates and may be beneficial by increasing moisture retention capacity.

Other considerations with respect to soil profile reconstruction during regrading operations are as follows. In general, a coarser-textured A horizon placed over a finer-textured subsoil is more suitable for promoting surface infiltration and for maximizing moisture storage while reducing surface runoff and erosion. Placing materials with a large textural difference over one another is undesirable, especially fine-textured material over coarse-textured material, because it acts to interrupt downward moisture flow and creates "perched water tables". Compacted zones should be eliminated when placing one material

over another because compaction impedes moisture flow.

Illustrations of regrading operations, seed bed preparation, and various erosion control techniques are shown in publications by Mills and Clar (1976) and USDA Soil Conservation Service (1977).

Mineralogical Relationships

Pyrite mineralogy. — Pyrite (FeS_2), formed in overburden materials under reducing conditions, oxidizes to form sulfuric acid when exposed to atmospheric oxygen or oxygenated waters. The rate of this reaction is increased as the particle size of the pyrite decreases and in the presence of sulfur-oxidizing bacteria (species of *Thiobacillus*). Framboidal pyrite, a fine-grained pyrite occurring in aggregates of individual crystals, usually $< 2\ \mu$ in size, oxidizes rapidly whereas large crystals react slowly. The overall reaction is shown in equation 1 below. When soil and overburden contains alkaline earth carbonates, such as lime, the acidity produced by pyrite is neutralized as shown in equation 2.

(1)

$$2FeS_2 + 7\text{-}\tfrac{1}{2}\ O_2 + 4H_2O \rightarrow 4H_2SO_4 + Fe_2O_3$$

(2)

$$H_2SO_4 + CaCO_3 \rightarrow Ca^{++} + SO_4^{=} + CO_2 + H_2O$$

Pyrite is detected in overburden materials by the qualitative method of Neckers and Walker (1952). The total acid potential of pyrite-bearing strata is quantitatively determined by analysis for total sulfur (Bardsley and Lancaster 1965) from which gypsum and water soluble sulfates are subtracted. The acid neutralization potential is determined on the basis of the overburden lime content. An "acid-base account" procedure (Smith and others 1976) is used to determine whether sufficient lime is present to neutralize the total potential acidity. Thus, pyrite in overburden materials should not be present in amounts sufficient to produce acid soil and acid drainage water if overburden is used as a soil substitute or is in contact with regraded subsoil. Prevention of acid soil formation is especially important because heavy metals, in general, become more available to plants and heavy metal concentrations increase in ground water as the soil becomes more acidic. Also, if the sulfuric acid produced by pyrite-oxidation is neutralized by lime, this can result in detrimental effects on ground water by raising the salinity content as soluble calcium and sulfate ions. The bicarbonate ion content may be reduced, however. A more thorough discussion of acidity development follows in volume II.

Clay mineralogy. — Swelling or expanding (2:1 type) clay minerals in soils and geologic overburden with excessive absorbed sodium undergo dispersion and decrease soil permeability to a greater degree than nonswelling clays. Identification and quantification of the less than $2\ \mu$ clay mineral fraction could be used as an additional criteria for determining critical exchangeable sodium levels. If the soil clay contains more than 65 percent 2:1 lattice swelling clays, lower limits of ESP could be imposed for the particular suitability class. Clay mineral analysis can be helpful in determining the suitability of overburden as a soil substitute. Overburden with a combination of both nonswelling and swelling clays would be preferable for soil profile reconstruction.

It is recommended that clay mineral analyses be run on only a few cores per site. Lateral variation in the clay mineral suite is generally not great within the area of a proposed surface mine. The possibility exists for greater vertical variation within different depositional strata or rock formations.

Sandstone mineralogy. — Microscopic examination of thin section samples of sandstone overburden units, although not a common practice, can provide useful data to aid in the correlation of overburden strata and to supplement other physical and chemical data on the friability, resistance to mechanical breakdown, weatherability, and pyrite content of these units. Little work has been completed on the petrographic characteristics of overburden in the western states. Studies of the mineralogical and textural characteristics and weatherability of Eocene (Wasatch) sandstones of the Powder River Basin, Wyoming, are presently under way by the authors of this report. In the Eastern United States, petrographic studies of Pennsylvanian

ge Sandstones by Grube and others (1972) ive revealed that some aspects of geologic overirden that are important to mine land reclamaon.

Petrographic studies of the Lower Mahoning ndstone, coupled with determination of the tal sulfur content of pulverized samples realed sufficient pyrite free rock material to ace in the oxidation zone of spoil heaps to oid acid pollution. These studies also reveal undant sandstone at depths below 6 m that ntain highly toxic materials that would proice prolonged sources of acid water pollution nless protected from oxidation by deep burial other means (Grube and others 1972).

Petrographic studies of the material filling e pore spaces between framework grains of ndstones revealed that moderately calcareous ndstones while hard at the time of excavation, ill break down relatively rapidly when left near e surface so that circulating waters are able to move the carbonate cement. Sandstones with gillaceous parting and clay matrix may also be rd at the time of excavation but will disinteate rapidly near the surface. The argillaceous ndstone are particularly useful where addional sand would be beneficial in the soil mith and others 1974).

race Element Toxicity elationships

Zinc and iron were considered in a general ay from the standpoint of deficiency to plants i section a. These same elements, with the exption of iron, as well as other trace elements ome of which are necessary for plant growth d others which are not) are discussed further i this section because of their environmental iportance. In addition to some of these elents being important as required plant nutrits, they are also of concern from the standint of toxicity to plants, animals and humans.

The trace elements considered in this sectn do not include all elements having potential ipact on the environment. Those included are rognized as perhaps being the most important ad/or likely to be a problem. In general, interest i trace elements tends to be based on the follving:

1. Those that are toxic to plants and/or animals (boron, selenium, and molybdenum).

2. Those that are toxic to fish (zinc).

3. Those that are toxic to humans and animals (selenium, arsenic, cadmium, and nickel).

This is not to say that other elements may not be of importance. Those listed are of highest interests, however, and, in general, may be the most likely to occur in quantities in available forms to plants and animals to cause problems.

Evaluation of potential trace element problems is complicated by the same sets of factors as those we find associated in soil fertility evaluations. Although plant uptake of these metals is one criterion for assessing their effects, different plants take up different quantities and the availability of these elements to plants and their mobility in environment is controlled by soil pH, drainage, moisture regime, and amount present in the soil. Also, nutrient interactions within the plant and/or animal control whether or not deficiency and/or toxicity may occur. Toxicity levels for plants, animals, and in soils have been reported for some elements, while critical levels for other elements have not yet been established.

Evaluation of trace element and plant nutrient relationships for geologic overburden is further complicated by the fact that if the deeply buried materials, that are relatively unaltered, are brought closer to the surface and subjected to the natural bio-geochemical weathering process, significant changes may occur in their chemical and physical properties through time. These changes may not be identifiable either through "total" or "available" chemical analysis performed on fresh materials.

Geologic material identification through mineralogical analyses can be a useful tool for identifying minerals having weathering reaction products that might be significant to the plant-soil-water environments. If mineralogical analyses are not performed, then other measures are needed to identify potential changes in geologic materials as a result of weathering, i.e., long term leaching effects and plant growth and plant tissue analyses.

It appears that a logical approach to the problem at the present time is (1) to know some-

thing about the kinds of soil or geologic materials in which these elements are likely to occur in high amounts, (2) to make some arbitrary assessment as to the availability of these elements to plants and/or animals based on an interpretation of the soil systems that occur or are likely to occur on the site, and (3) if a problem is suspected, to make an appropriate choice of a chemical extractant which will indicate the potential availability to plants and/or mobility of the element in the bio-geochemical environment.

The data provided in table 18 show, in general, the amounts of some trace elements found in rocks that form soil parent materials. This information enables us to anticipate with some degree of confidence the approximate amount of a trace element that might be present if we identify the nature of the geologic material(s) with which we are working.

In addition, the data in table 18 identifies the soil conditions in which the various trace elements may be potentially more available to plants, and also more mobile in the soil, and thus subject to leaching.

Soil Erosion Relationships

Some accepted procedures for evaluating wind and water erosion potential, and identifying regraded and stockpiled areas follows:

The methods discussed have certain limitations. It is suggested that the references listed be carefully reviewed to ensure that the methods are not misinterpreted relative to their applicability for assessing erosion for a given condition. The procedures outlined can be an excellent tool for assessing the relative erosion potential that might exist, but must be used with discrimination and with adequate background information relative to the values that are used for assessing the impact of a particular variable.

Wind erosion. — Overall susceptibility to wind erosion has been demonstrated to be the result of a number of variables and has been expressed in the form of the equation

$$E = f(I\ K\ C\ L\ V)$$

where:

E = the predicted average annual soil lo expressed in tons/acre/year.

I = soil erodibility. This is the inhere potential of the soil to erode under a "bare" su face condition.

K = a soil surface roughness factor. Ma times, roughening of the soil surface by mecha ical means can, on some soils, completely st wind erosion for at least a short term peri This factor should be seriously considered a "short term" practice as part of an erosion c trol plan. Guides are available for calculating s face roughness for specific site situations. T practice would be most useful on soils havi "moderate" wind erosion susceptibility becau they generally leave a cloddy, as well as rough surface condition after treatment, both of wh are effective in controlling wind erosion.

C = climatic factor. This factor is evalua based on the average wind velocity and on precipitation-evaporation index for a given ar

L = The unsheltered distance along prevailing wind direction. Attempts should made to avoid creating unsheltered or bare areas which are moist subject to prevailing wi For example, creating a bare area on the wi ward side of a knoll greatly increases suscepti ity to wind erosion and stabilization procedu would have to recognize this situation if it exi Otherwise, stabilization efforts often will fail.

V = vegetative cover. This variable wind erosion evaluation considers three co tions: (1) quantity of residue, (2) kind of due, and (3) the orientation of the residue.

Water erosion. — Factors important evaluating water erosion potential and a basis developing erosion control management prac have also been combined in the form of the lowing equation-like expression:

$$A = R\ K\ L\ S\ C\ P$$

where:

A = computed soil loss expressed in t acre/year.

Table 18. — General relationships of occurrence and availability of trace elements in soil and/or geologic overburden

General abundance and occurrence of trace elements in geologic and soil materials in p/m (Bowen 1966; Swain 1955; Taylor 1961) (Total concentration)

	Mn	B	Zn	Cu	As	Pb	Mo	Se	Cd	Ni
Earth crust	950	10	70	55	1.8	12.5	1.5	05	2	75
Sedimentary rocks										
Shale	850	100	95	45	13 0	20.0	2 6	60	30	68
Sandstone	50	35	16	5	1 0	7 0	20	05	05	2
Limestone	1100	20	20	4	1 0	9.0	4	08	035	20
Soils										
Range	100-4000	2-100	10-300	2-100	1 0-50	2 0-200	2-5 0	01-2 00	01-7 00	— —
Mean	850	10	50	20	6 0	10 0	1 0	20	06	40

Concentrations of trace elements in the surface layers of soils in Powder River Basin — in p/m (after Keefer and Hadley 1976)

	Mn	B	Zn	Cu	As	Pb	Mo	Se	Cd	Ni
Depth 0-1 inch (0-2 5 cm)										
Range	70-1000	<2 0-70	28-93	3-30	— —	10-30	<3-20	— —	— —	<5-30
Mean	280	31	62	16	7 2	18		20	—	15
Depth 6-8 inches 15-20 cm										
Range	100-700	<20-70	25-104	5-50	— —	10-100	<3-5	—	— —	<7-50
Mean	250	28	64	18	8 2	18	—	14		16

[1] Providing specific criteria for evaluating potential toxicity and/or deficiency of these elements is impractical and even dangerous because of the variability in tolerance to these elements by different plants, even within the same species — animals and humans. The only appropriate manner for handling these questions at the present time is to review recent literature and determine if data that are available actually apply to a particular situation. Suggested references are: Chapman and others 1966, Mitchell 1964, Connor and others 1975, Cannon and others 1972, Shacklette 1972, Hemphill 1973, Prabhakarannair 1969, Connor and others 1976, Cragg 1973, Norman and others 1968.

General soil conditions where elements are mobile or available to plants

Element	Soil condition	Remarks[1]
Mn	Most available under acid soil conditions, neutral or alkaline soil conditions may cause deficiencies	Manganese toxicities in plants generally occur on very acid soils. Deficiencies may occur on neutral or alkaline soils. Excess Mn may restrict plant growth
B	Low precipitation, alkaline soil conditions	Boron toxicity can occur in arid areas where sodium and calcium borates occur in soils. The safe limits of available Boron content between deficiency and toxicity are narrow
Zn	Soil low in $CaCO_3$ acid soil conditions	Zinc toxicities can occur on acid soils that are heavily fertilized with zinc fertilizers. Zinc tends to accumulate at or near the surface of the soil
Cu	Acid soil conditions	Deficiency of copper occurs on sandy alkaline soils that have been well leached. Toxicity of copper can occur on soils that have been subject to applications of sprays containing copper
As	Alkaline soil conditions	No evidence that arsenic is essential for plant growth. Toxicity generally occurs in areas that have accumulated arsenic in the soils through total spray compounds
Pb	Acid soil conditions	Lead accumulated in surface horizons of many soils does not appear to be readily available to plants. Lead may be absorbed by plants from polation and then be toxic to animals
Mo	Wet soils and neutral to alkaline soil conditions	Heavy applications of phosphatic fertilizers will increase molybdenum uptake by plants. Excessive amounts of molybdenum are toxic to grazing animals
Se	Alkaline soil conditions with well oxidized environment	Selective plants such as Astragalus and Stanleya generally accumulate selenium and may cause poisoning in grazers. Associated with sedimentary rocks
Cd	Mildly alkaline to acid soil conditions	Not usually toxic to plants. Cadmium may be absorbed by plants from pollution and may cause toxicity to grazing animals
Ni	Acid soil conditions	Nonessential for plants and animals. The amount of nickel absorbed ranges widely among species

R = the rainfall factor. An index which is the measure of the erosive force of specific rainfall. This value can be expressed as a mean over an annual period or for short periods of time.

K = the soil erodibility factor. A relative value expressed from 0 to 1.0 which reflects the inherent potential of soil to erode by water when exposed.

LS = slope length and degree factor.

C = crop cover or management factor.

P = erosion control practice factor such as contouring, terracing, etc.

Numerical values for each of the six factors have been determined from field experience and research data. Values for use in the wind erosion equation also are available (USDA Soil Conservation Service 1977 a, b, c).

Developing a Soil and Geologic Overburden Laboratory Characterization Program

The main objective in developing a soil and geologic overburden laboratory characterization program is to avoid mass sample characterization by minimizing the number and/or kinds of analyses that are performed. This is done without sacrificing quality and kinds of data needed for making the assessments necessary.

The Bureau of Reclamation, U.S. Department of the Interior, has for many years based the level and intensity of laboratory characterization on an approach called "screenable soil characterization as related to land reclamation" (personal communication, Mr. Richard Piper, U.S. Bureau of Reclamation, Denver, Colo.). In screenable characterization a multiphase program is developed which minimizes the number and kinds of analyses to be performed. This approach emphasizes that the number and types of laboratory studies to be carried out will be determined by area conditions, particularly variability of soils and land types, and the controlling specifications and needs. Thus, the laboratory characterization must be coordinated from the very beginning with the field investigations. Using this concept, the information in table 19 was developed as an example for determining data needs for evaluating soil and/or geologic overburden material as plant growth media and effects on environmental quality. The approach, as presented in table 19, may require modification based on present Federal, State, and local regulations, as well as particular site characteristics. It does, however, provide a basic framework for developing a data needs plan.

Interpretation and Application of Ground and Surface Water Data

The interpretation and uses of ground and surface water data relative to surface mining are highly site specific. Here it is possible to provide only general guidelines and procedures. A general description of research and interpretation procedures for ground water and ground water chemistry is provided by Freeze and Cherry (1979).

SURFACE AND GROUND WATER QUALITY

An important purpose of collecting data on the quality of surface and ground waters is to provide a baseline from which changes attributable to mining can be detected. For purposes of premining and postmining planning and decision making, it is necessary to identify and understand, quantitatively, the role that the study site plays in determining the quality of waters used internal and external to the study site. Only then is it possible to rationally project potential changes caused by the mining operations. A number of specific steps must be accomplished.

A first step is to combine the water quality data with the estimated discharges of ground and surface waters to determine chemical discharge from the site to potential receiving waters. The chemical discharge can be computed in terms of specific ions of particular concern, in terms of total dissolved solids, or both. Knowledge of the quality and discharge of the receiving waters below the points of inflow from the study site assist in determining the contribution from the study area. The framework in which

Table 19. — Example of an approach for determining interpretative data needs

Situation	Data needs
	A. Soil resources
1. Identify current soil resource status.	a. Federal Register (Jan. 31, 1978) and any State criteria available through the Soil Conservation Service (SCS).
a. Important and prime farmlands. b. Land capability.	b. Identify management practices needed to maintain or increase productivity by utilizing existing soil and land interpretive classifications utilized by the SCS, the United States Bureau of Reclamation, and other agencies.
2. Determine plant growth media potential of given soil resource.	a. Soil isopach maps developed from soil inventory are used to determine distributions and extent of soil materials. b. Laboratory analyses needed to determine quality of soil resources: salinity, sodium, pH, organic matter, texture, available N, P and K, percent calcium carbonate, and percent saturation (water). Other laboratory analyses for trace elements or heavy metals in the soil should be considered dependent on type of material and in which soil has developed and the chemical status of existing soil systems. Table 18 shows normal levels in rock and soils. This will aid in determining whether or not particular elements may be suspect.
3. Determine current and potential erosion.	Variables for determining wind and water erosion should be identified (USDA Soil Conservation Service 1977a,b,c).
	B. Geologic overburden resouces
4. Evaluate geologic overburden for plant growth media. (This step would be carried out if the soil resource evaluation indicates that it is necessary to utilize these materials as plant growth media.)	a. Identify distribution and extent of geologic strata from lithological core data. Sampling according to variances as shown by lithologica core characterization. b. Laboratory analyses of select geologic overburden to determine quality as a plant growth media: salinity, sodium, pH, organic matter, texture, available N and P, pyrite, percent saturation (water), percent calcium carbonate, percent gypsum, and erosion potential.
5. Evaluate geologic overburden for environmental concerns such as placement effects on ground water quality.	Select geologic overburden to determine effect on environmental quality: salinity, sodium, pH, organic matter, pyrite, percent calcium carbonate, and percent gypsum. Additional analyses for other factors such as heavy metals can initially be determined based on the data shown in table 18.

the analysis is applied is that of a combined expression for water and chemical mass balance (Rowe and McWhorter 1978; Kunkle 1965; Pinder and Jones 1969; Visocky 1970). It is sometimes possible to refine estimates of surface and ground water inflow to the receiving waters by this procedure. For example, suppose the discharge and total dissolved solids (TDS) concentration are measured at both ends of a stream reach receiving ground and surface water inflows from the area of concern. The measured gain of water over the reach must be accountable by surface and ground water inflows, taking into account such factors as diversions, evaporation, and transpiration. Similarly, the measured gain in chemical discharge (TDS multiplied by water discharge) must be accountable by chemical discharge from surface and ground water inflows. Ideally, an overall balance of both water and chemical discharge should be achieved. This is rarely possible without making reasonable adjustments of contributing factors. Often it is advantageous to perform such analyses for selected sub areas and reaches of receiving waters and over selected time intervals, when one or more contributing factors can be set to zero.

Once a satisfactory water and chemical balance has been achieved, the investigator is in a position to predict how the quality and quantity of the receiving waters will be changed by changes in the quality and quantity of inflow from the study area. At this point it is necessary to estimate the changes that can reasonably be expected to occur as the result of mining. Among the factors that must be considered are changes in recharge and storage as a result of mining, interception of surface and ground water by the pit, changes in evapotranspiration, modifications of the routes and quantities of surface runoff, and the pick up of additional contaminants.

Accurately predicting such changes is difficult, and only some very general guidelines can be provided. Discussion of potential changes in the quantities of recharge, ground and surface water runoff, and evapotranspiration are contained in the next subsection. The following is a brief presentation of one method for estimating postmining quality of combined surface and ground water runoff.

The disturbance of the naturally occurri sequence of strata exposes fresh surfaces f contact by water and, therefore, enhances t opportunity for water to pick up addition soluble materials. Experience at one site Colorado showed that the TDS concentrati (as indicated by electrical conductivity) in wa that had passed through the spoils was abc equal to that in extracts from saturated samp of the spoil (Rowe and McWhorter 1978). Oth experience in Montana and North Dakota h not verified the equality of these measuremen however. The present state of knowledge see to support only the rough rule of thumb th the dissolved solids concentration in spoil wa will be on the order of 1 to 3 times the conc tration in extracts from saturated pastes prepa from the overburden (Rowe and McWhor 1978; Van Voase 1978).

In general, the quality (with respect to solved solids) of overland flow from disturb lands is not greatly different from that in the disturbed state (Rowe and McWhorter 197 This is particularly true if existing topsoil is placed on the spoils following mining. App ently, pick up of dissolved solids by overl flow is not as great as for subsurface flows cause the thin layer of material in contact w overland flow is rapidly leached and, becaus smaller contact times, among other reasons.

Rowe and McWhorter (1978) presen simple model based upon the concepts of m balance described in the foregoing paragra that may be useful for making rough estim of the anticipated effect of mining on the T in combined surface and ground water run Their model is

$$P_t = \frac{KR\ f_{sn}P_{sn} + (1-f_{sn})P_{gn} + f_{sm}P_{sm} + (1-f_{sm})P_{gm}}{1 + KR}$$

where:

P_t = the mean TDS in combined sur and groundwater runoff from the total waters comprised of both mined and natural lands.

K = The ratio of total drainage per area (including both surface and ground w

noff) on the undisturbed portion of the water-ed to the total drainage per unit area from the ned land.

R = The ratio of the area of undisturbed nd to the area disrupted by mining.

P_{sm} = mean TDS concentration in surface noff from the mined area.

P_{gm} = mean TDS concentration in ground iter runoff from the mined area.

f_{sm} = the fraction of total drainage from ned area that is overland flow.

P_{sn} = mean TDS concentration in surface noff from the natural area of the watershed.

P_{gn} = mean TDS concentration in ground ter runoff from the natural area of the water-d.

f_{sn} = the fraction of total drainage from natural area that is overland flow.

is model is based on the assumption of zero t change in watershed storage and, therefore, parameters represent means over a period for ich this assumption is approximately true. A nimum of 1 year is recommended.

A brief example follows. Suppose that pre-ne monitoring of the quality and quantity of ound and surface water flows on the water-ed to be mined yielded P_{sn} = 210 mg/l, P_{gn} 900 mg/l, and that f_{sn} = 0.10. Also, satura-n extracts prepared from overburden samples hibited a mean TDS of 2 300 mg/l, from which is estimated that the TDS of ground water in spoils will be 4 600 mg/l. Thus, P_{gm} = 4 600 g/l. Topsoiling is planned so it is resonable to ume P_{sm} = P_{sn} = 210 mg/l. Reclamation ins call for revegetation that can be expected be about equal to the premining vegetation. ading of the mined lands is not expected to produce the premining drainage patterns, wever. Numerous small basins with no outlet formed and this causes reduced surface run-, longer surface retention of water, and in-ased infiltration opportunity relative to un-turbed land. Thus, it is anticipated that total combined surface and ground water runoff from the mined land will be reduced relative to the undisturbed area by 15 percent. This yileds K = 1/0.85 = 1.18. The difference is accounted for by increased transpiration by plants due to the increased quantity of water available in the root zone. Also, because of the lack of good surface drainage on the regraded mined land, it is estimated that the fraction of total drainage from the mined land that is overland flow will be reduced relative to the natural condition. Therefore, f_{sm} is set equal to 0.05. Finally, the mining plans call for 22 percent of the watershed to be mined. This yields R = 0.78/0.22 = 3.55.

Values for all of the parameters on the right side of the equation are now available. Substituting and carrying out the computations yields P_t = 1 515 mg/l. This is the anticipated postmining value for the mean annual, discharge weighted, TDS concentration in total drainage from the watershed in which the mine is located. The corresponding premining value is 831 mg/l. In this case, mining 22 percent of the watershed nearly doubles the mean TDS concentration in the watershed drainage.

The foregoing is a demonstration of one way in which water quality and overburden data can be utilized in premine planning and decision making. The model is not applicable in all cases, of course, and other analysis procedures may be required for particular studies.

Water quality data is sometimes very useful for assisting in the understanding of the subsurface hydrologic system. For example, the proportion of surface water and ground water in the discharge of a pumping well can sometimes be determined by knowing the quality of the surface water, the quality of the unmixed ground water, and the quality and discharge of the mixture from the well (Hem 1970). Sudden changes in water quality during a pumping test can sometimes be interpreted as contributions from different zones with dissimilar water quality. Water quality in different zones may provide insight into the degree of interconnection between adjacent aquifer zones, as another example.

PIEZOMETRIC SURFACE MAPS AND FLUCTUATIONS

Ground water level data from a network of observation wells can be used to construct piezometric surface and water table maps. Such maps are prepared by connecting points of equal water level elevation to form a pattern of contours similar to those on a topographic map. These maps provide information concerning ground water flow direction, quantities of flow (when combined with transmissivity), and likely areas of recharge and discharge. Geologic information on stratigraphy, structure, faults, etc., should be fully utilized during the preparation and interpretation of piezometric surface maps.

An important use of such maps is to compute the quantities of ground water entering and leaving the study area, or possibly, to and from surface water bodies. These quantities are required for use in the water and chemical mass balances discussed in the previous subsection. Premining flow patterns, displayed as a piezometric map, are an aid to the determination of inflow to the mining pit, the estimation of the area over which the piezometric surface can be expected to be disturbed in both the mining and postmining phases, and the postmining flow pattern. The elevation of water levels in wells relative to the elevation of streams, ponds, springs, etc., often provides the most significant information available concerning the interrelationships between surface and ground waters. Similarly, relative elevation of water levels in different aquifers at the same location provides information on the degree of hydraulic interconnection between aquifers, especially when one of the aquifers is being pumped.

Figure 14 is an example of a piezometric surface map prepared for and overburden aquifer at a potential mine site. The direction of ground water flow is toward the northeast in this case. Comparision of piezometric surface elevations in the potential mine area with those in a shallow alluvial aquifer adjacent to the site on the east and north sides indicated that ground water discharged from the potential mine site into the alluvial aquifer. The gradient (slope) of the piezometric surface is about 0.006. These data, together with measured values for transmissivity of $7x10^{-3}$ ft^2 per min, and the area thr[illegible] which flow is occurring, yields an estimated [illegible] acre-ft/yr of ground water discharge into [illegible] alluvial aquifer. Knowledge of the quality of [illegible] ground water in the overburden aquifer and [illegible] alluvial aquifer permits the estimation of th[illegible] fluence of the overburden waters on both [illegible] quantity and quality of the waters contained [illegible] the alluvial aquifer.

Water level fluctuations can sometimes [illegible] used to estimate recharge when values for [illegible] storage coefficient or apparent specific yield [illegible] known. Multiplying the observed change in wa[illegible] level by the storage coefficient or the appa[illegible] specific yield gives the volume of water per [illegible] area that has been added or removed from [illegible] aquifer. Factors other than recharge and [illegible] charge sometimes cause water levels in wel[illegible] fluctuate, however. Barometric pressure cha[illegible] often cause water levels in wells penetrating [illegible] fined aquifers to change by as much as se[illegible] centimeters. Water levels should be corre[illegible] with barometric pressure and precipitatio[illegible] help assure a correct interpretation.

Figure 15 shows measured water level[illegible] three wells in a potential mine site. The flu[illegible] tions apparent in the lower two graphs corr[illegible] well with each other, and these short term f[illegible] tuations represent response to atmospheric [illegible] sure fluctuations indicating that both wel[illegible] completed in a confined aquifer. The [illegible] graph shows the water level in a well penetr[illegible] an unconfined aquifer in the same area. The [illegible] clusions drawn from these records was sub[illegible] tiated by geophysical and geological data a[illegible] site. The time period over which these data [illegible] collected is too short to draw any conclu[illegible] concerning the indicated trends relative [illegible] charge or discharge. Nevertheless, this exa[illegible] demonstrates how water level fluctuation [illegible] can assist in the interpretation of geologi[illegible] geophysical information.

ANALYSIS OF AQUIFER TEST DATA

It is apparent from the discussions i[illegible] foregoing subsections that values of tra[illegible] sivity, storage coefficient, and apparent sp[illegible] yield are required for several of the com[illegible]

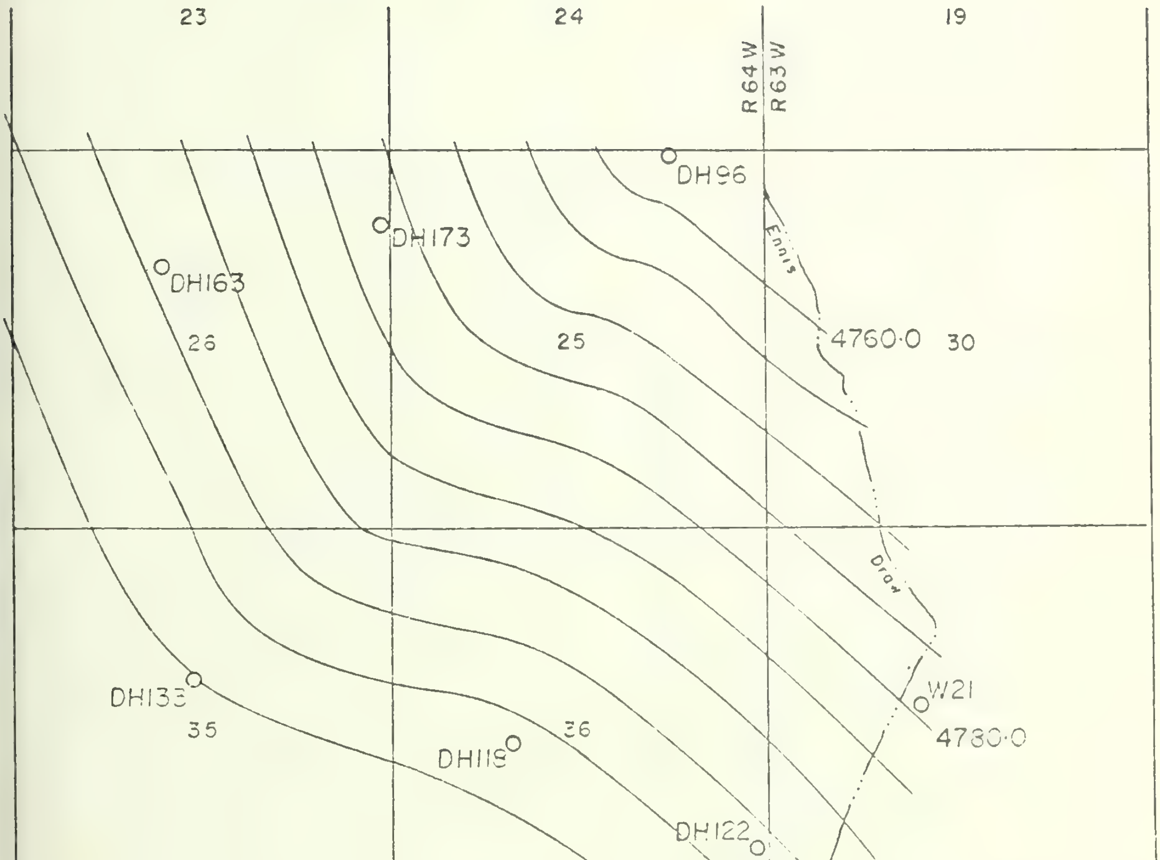


Figure 14. Piezometric surface of overburden aquifer in October 1978.


DH 122
DH 60
DH 117
16.0
40.50
40.60
40.70
21.60
21.70
21.80
Time - Days
52

tions. Other important questions such as mine inflow, the extent of disturbance of the piezometric surface, and recovery time also require knowledge of the hydraulic coefficients. The use of the hydraulic coefficients in such calculations is outlined subsequently. In the present subsection, the analysis of the aquifer test data from which the coefficients are derived is discussed.

Aquifer test data analysis involves the graphical transformation of raw field data into calculated values of the aquifer parameters (Stallman 1971). These aquifer parameters may be obtained from the observation of two relationships that occur during an aquifer test (Johnson, Inc. 1974): (1) The rate of drawdown with respect to time at any point within the cone of depression (time-drawdown graph); and (2) shape and position of the cone of depression with respect to distance at some time during the aquifer test (distance-drawdown graph).

The Theis, Jacob, recovery, and slug test methods are based on observation of the time-drawdown relationship, and the distance-drawdown test method is based on observations of the distance-drawdown relationship. All methods of aquifer test data analysis discussed herein are based on the following assumptions (Stallman 1971; Johnson, Inc. 1972).

1. The aquifer is homogeneous and isotropic.

2. The aquifer is of uniform thickness.

3. The pumping well completely penetrates the aquifer.

4. The natural ground water gradient is negligible.

5. Laminar flow conditions exist throughout the aquifer.

6. The aquifer is of infinite areal extent.

7. The well has been properly developed.

8. The well discharge is equal to the aquifer discharge.

The impact of boundary effects and well development on aquifer test data analysis is discussed later. Certain additional assumptions are invoked for particular types of analyses.

Theis analysis (adapted from McWhorter and Sunada 1977). — The Theis method of aquifer test analysis uses the following procedures:

1. On transparent log-log paper, plot drawdown vs r^2/t (r is the distance between the pumping and observation wells). This is known as the field curve.

2. From table 20 prepare a log-log plot of W(u) vs u. This is known as the type curve. Note: both the field and type curves must be plotted on the same size log-log paper.

3. Superimpose the field curve over the type curve, keeping both axes parallel. Adjust the position of the field curve until a best fit is made between the field data and the type curve.

4. Select any arbitrary "match" point and record its related coordinates W(u), u from the type curve and s, r^2/t from the field curve (fig. 16).

5. The values of W(u), u, s, r^2/t corresponding to the match point are inserted into the following formulas to determine the transmissivity and storage coefficient (or apparent specific yield):

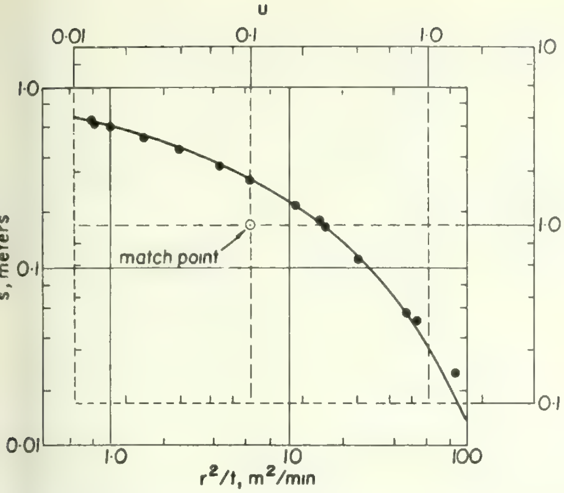
$$T = \frac{QW(u)}{4\pi s} \qquad S = \frac{4Ttu}{r^2}$$

where:

Q	=	well discharge during the pump test
s	=	drawdown
S	=	storage coefficient or apparent specific yield
T	=	transmissivity
r	=	distance between pumping and observation wells
W(u),u	=	match point coordinates from the type curve.

Table 20. — Values of W(u) (From McWhorter and Sunada 1977)

N/u	$N \times 10^{-15}$	$N \times 10^{-14}$	$N \times 10^{-13}$	$N \times 10^{-12}$	$N \times 10^{-11}$	$N \times 10^{-10}$	$N \times 10^{-9}$	$N \times 10^{-8}$	$N \times 10^{-7}$	$N \times 10^{-6}$	$N \times 10^{-5}$	$N \times 10^{-4}$	$N \times 10^{-3}$	$N \times 10^{-2}$	$N \times 10^{-1}$	N
1.0	33.9616	31.6590	29.3564	27.0538	24.7512	22.4486	20.1460	17.8435	15.5409	13.2383	10.9357	8.6332	6.3315	4.0379	1.8229	0.2194
1.5	33.5561	31.2535	28.9509	26.6483	24.3458	22.0432	19.7406	17.4380	15.1354	12.8328	10.5303	8.2278	5.9266	3.6374	1.4645	0.1000
2.0	33.2684	30.9658	28.6632	26.3607	24.0581	21.7555	19.4529	17.1503	14.8477	12.5451	10.2426	7.9402	5.6394	3.3547	1.2227	0.04890
2.5	33.0453	30.7427	28.4401	26.1375	23.8349	21.5323	19.2298	16.9272	14.6246	12.3220	10.0194	7.7172	5.4167	3.1365	1.0443	0.02491
3.0	32.8629	30.5604	28.2578	25.9552	23.6526	21.3500	19.0474	16.7449	14.4423	12.1397	9.8371	7.5348	5.2349	2.9591	0.9057	0.01305
3.5	32.7088	30.4062	28.1036	25.8010	23.4985	21.1959	18.8933	16.5907	14.2881	11.9855	9.6830	7.3807	5.0813	2.8099	0.7942	0.006970
4.0	32.5753	30.2727	27.9701	25.6675	23.3649	21.0623	18.7598	16.4572	14.1546	11.8520	9.5495	7.2472	4.9482	2.6813	0.7024	0.003779
4.5	32.4575	30.1549	27.8523	25.5497	23.2471	20.9446	18.6420	16.3394	14.0368	11.7342	9.4317	7.1295	4.8310	2.5684	0.6253	0.002073
5.0	32.3521	30.0495	27.7470	25.4444	23.1418	20.8392	18.5366	16.2340	13.9314	11.6280	9.3263	7.0242	4.7261	2.4679	0.5598	0.001148
5.5	32.2568	29.9542	27.6516	25.3491	23.0465	20.7439	18.4413	16.1387	13.8361	11.5330	9.2310	6.9289	4.6313	2.3775	0.5034	0.0006409
6.0	32.1698	29.8672	27.5646	25.2620	22.9595	20.6569	18.3543	16.0517	13.7491	11.4465	9.1440	6.8420	4.5448	2.2953	0.4544	0.0003601
6.5	32.0898	29.7872	27.4846	25.1820	22.8794	20.5768	18.2742	16.9717	13.6691	11.3665	9.0640	6.7620	4.4652	2.2201	0.4115	0.0002034
7.0	32.0156	29.7131	27.4105	25.1079	22.8053	20.5027	18.2001	15.8976	13.5950	11.2924	8.9899	6.6879	4.3916	2.1508	0.3738	0.0001155
7.5	31.9467	29.6441	27.3415	25.0389	22.7363	20.4337	18.1311	15.8280	13.5260	11.2234	8.9209	6.6190	4.3231	2.0867	0.3403	0.0000658
8.0	31.8821	29.5795	27.2769	24.9744	22.6718	20.3692	18.0666	15.7640	13.4614	11.1589	8.8563	6.5545	4.2591	2.0269	0.3106	0.0000376
8.5	31.8215	29.5189	27.2163	24.9137	22.6112	20.3086	18.0060	15.7034	13.4008	11.0982	8.7957	6.4939	4.1990	1.9711	0.2840	0.0000216
9.0	31.7643	29.4618	27.1592	24.8566	22.5540	20.2514	17.9488	15.6462	13.3437	11.0411	8.7386	6.4368	4.1423	1.9187	0.2602	0.0000124
9.5	31.7103	29.4077	27.1051	24.8025	22.4999	20.1973	17.8948	15.5922	13.2896	10.9870	8.6845	6.3828	4.0887	1.8695	0.2387	0.0000071



igure 16. Matching the type curve with drawown data.

xample (McWhorter and Sunada 1977)

Estimate the transmissivity and apparent pecific yield of an aquifer from the following ata.

$r = 20$ m			$Q = 1.872$ m^3/min		
(meters)		0.025	0.050	0.055	0.110
$^2/t$ (m^2/min)		88.9	53.3	47.1	25.0
	0.170	0.180	0.220	0.300	0.370
$^2/t$	16.7	15.1	11.1	6.25	4.12
	0.450	0.530	0.620	0.640	0.650
$^2/t$	2.47	1.55	0.98	0.82	0.78

Following the procedures described previusly, the data are plotted on log-log paper then uperimposed on the type curve. Figure 16 illusates the field curve superimposed on the type urve with a selected match point. The match oint coordinates are:

$W(u) = 1.0$, $u = 0.1$, $s = 0.183$, $r^2/t = 6.2$.

rom before,

$$T = \frac{QW(u)}{4\pi s} = \frac{(1.872)\,(1.0)}{4\pi(0.183)}$$

$$= 0.814 \text{ m}^2/\text{min}$$

$$S_{ya} = \frac{4Ttu}{r^2} = \frac{4(0.814)\,(0.1)}{6.2} = 0.053.$$

In addition to the assumptions listed previously, this method assumes that the aquifer discharge is constant. In applications where the transmissivity is very low, the aquifer discharge to the well may not be constant, even for a constant pump discharge. This is because the pump derives a portion of its discharge from water standing in the well bore. Correction of the pump discharge, using measured drawdowns in the pumped well, may be necessary to determine an acceptably accurate value for Q in the above equations.

Jacob analysis (adapted from McWhorter and Sunada 1977). — The Jacob method is subject to the same restrictions as the Theis analysis. An additional restriction imposed on this method is that the test must be conducted for a sufficiently long time such that $u < 0.01$, where $u = r^2/4\alpha t$ and $\alpha = T/S$ for confined aquifers; $\alpha = T/S_{ya}$ for unconfined aquifers.

The Jacob method uses the following procedures.

1. Using semi-log paper, plot drawdown on the coordinate axis vs. time on the logarithmic axis (fig. 17). The plot will be a straight line if the test was conducted for a sufficiently long period.

2. From this plot, compute the change in drawdown over one log cycle.

3. The change in drawdown over one log cycle is inserted into the following equation along with the other field data to determine transmissivity.

$$T = 2.303Q/4\pi\Delta s$$

where:

Q = discharge

Δs = change in drawdown over one log cycle.

4. To determine the storage coefficient or apparent specific yield, extrapolate the straight line portion of the data plot to the horizontal axis (s=0). Determine the value of t_o where the straight line intersects the horizontal axis.

5. Insert the value of t_o along with the appropriate data into the following formula:

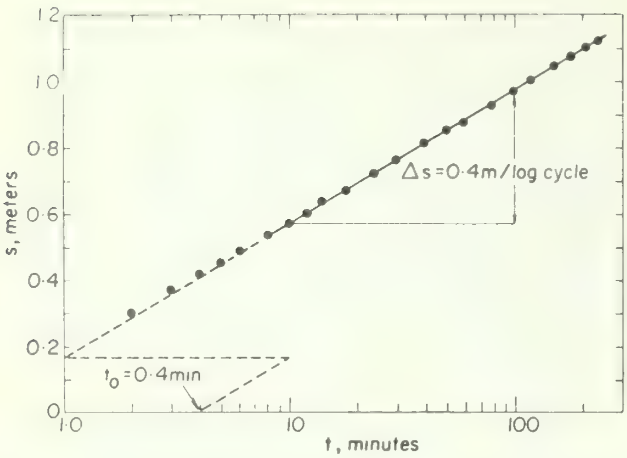


Figure 17. Example of the Jacob method for determining aquifer properties.

$$S = 2.246Tt_o/r^2$$

where:

r	=	radial distance between the observation well and the pumping well
T	=	transmissivity determined previously
t_o	=	time where drawdown = 0
S	=	storage coefficient (confined) or apparent specific yield (unconfined).

Example (McWhorter and Sunada 1977)

Given the following data, determine the transmissivity and the storage coefficient.

$r = 61$ m $\qquad Q = 1.844\ m^3/min$

t(min)	1	2	3	4	5
s(meters)	0.200	0.300	0.370	0.415	0.450
t	6	8	10	12	14	18
s	0.485	0.530	0.570	0.600	0.635	0.670
t	24	30	40	50	60	80
s	0.720	0.760	0.810	0.850	0.875	0.925
t	100	120	150	180	210	240
s	0.965	1.000	1.045	1.070	1.100	1.120

The data are plotted as shown in fig. 17. From the foregoing,

$$T = 2.303Q/4\pi\Delta s$$
$$= [2.303(1.894)]/[4\pi(0.4)]$$
$$= 0.868\ m^2/min.$$

Extrapolation of the straight line yields t_o = minutes at s = 0.

$$S = 2.246Tt_o/r^2$$
$$= [2(2.246)(0.868)(0.4)]/(61)^2$$
$$= 2.0\times10^{-4}.$$

Before we can accept these results, we mu sure that $u \leq 0.01$. For a confined aquif = $Sr^2/4Tt$. The minimum test duration tim which $u \leq 0.01$ is given by t = r^2S = $[(61)^2(2.0\times10^{-4})]/[4(0.868)(0.01)]$ = min. Therefore, only data points for t>21 should be used in the determination of straight line. Using data for which u<0.01 c a deviation of about 6 percent from the analysis results.

Because of the restriction that u mu less than 0.01 for the Jacob method of an to be applicable, this procedure is usually to analyze drawdown data collected or pumped well itself. Thus, it is often used f analysis of data from the drawdown/specif pacity type test that was discussed previo Again, well-bore storage is likely to be a s cant source of error in very tight aquifers, the pump discharge is appropriately correct

Specific capacity analysis (adapted Walton 1970; USDI 1977). — No atten made in this method to obtain values f storage coefficient or apparent specific Rather the procedure is to estimate an app ate value for the storage coefficient based whether the aquifer is confined or uncon and from experience in the area (if an storage coefficient of 10^{-4} and an apparen cific yield of 0.1 will suffice, if no informa available. Transmissivity T is plotted again responding values for specific capacity (log-log paper from the equation

$$Q/s = 4T/[\ln(\frac{4\pi T}{Sr_w^2} - 0.5772)],$$

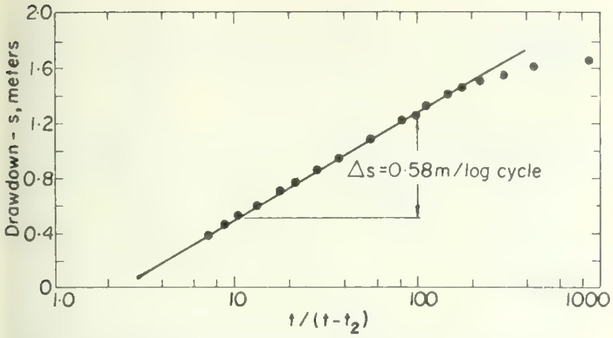


Figure 18. Water levels in a recovery test.

using the estimated value for S and a number of arbitrary values of T. The radius of the well is r_w. The value of time used in the computation is the pumping time at which the drawdown *s* was measured. The value of transmissivity that corresponds to the observed specific capacity is read from the graph.

The USDI (1977) reference presents a table from which the transmissivity can be estimated from knowledge of only specific capacity. The value so obtained is only a rough estimate.

Recovery test analysis (adapted from McWhorter and Sunada 1977). — The recovery test is conducted immediately after the pump is shut off at the end of the pump test. An additional restriction imposed on this method is that the value of u must be less than 0.01, where $u = r^2/4\alpha t$ as stated previously.

The recovery test uses the following procedures:

1. Record the total length of pumping time when the pump is shut off (t_p).

2. Using semi-log paper, plot drawdown on the coordinate axis vs $t/t\text{-}t_p$ on the logarithmic axis (fig. 18). Note, t is the time since pumping began, t_p is the total pumping time ($t > t_p$).

3. From this plot, compute the change in drawdown over one log cycle.

4. Insert the change in drawdown over one log cycle into the following equation to determine transmissivity:

$$T = 2.303Q/4\pi\Delta s$$

5. To determine the storage coefficient or apparent specific yields, extrapolate the straight line portion of the data plot to the horizontal axis. Determine t_o at the intersection of the straight line and horizontal axis.

6. Insert the value of t_o into the following formula:

$$S = 2.246Tt_o/r^2$$

where:

- r = distance between observation and pumping wells
- T = transmissivity
- t_o = time when drawdown = 0
- S = apparent specific yield or storage coefficient.

Example (McWhorter and Sunada 1977)

Given the following data determine the transmissivity and the storage coefficient.

$Q = 1.79\ m^3/min$, $r = 4.6$ m, pumping time $t_p = 443$ min.

s(meters)	1.640	1.595	1.535	1.490	1.445
t(min)	443.5	444	444.5	445	445.5

s	1.400	1.305	1.235	1.200	1.060	0.930
t	446	447	447.5	448.5	451	455

s	0.845	0.755	0.700	0.590	0.521	0.451
t	459	464	469	479	489	499

s	0.384
t	514

Calculate $t/t\text{-}t_p$ for each of the above data points and plot as shown in fig. 18. From the foregoing,

$$T = 2.303Q/4\pi\Delta s$$
$$= [2.303(1.79)2/[4\pi(0.58)]$$
$$= 0.566\ m^2/min.$$

Extrapolation of the straight line yields $t/t\text{-}t_p = 2.2$ min. From before,

$$S = 2.246Tt_o/r^2$$
$$= [2.246(0.566)(2.2)]/(4.6)^2 = 0.13.$$

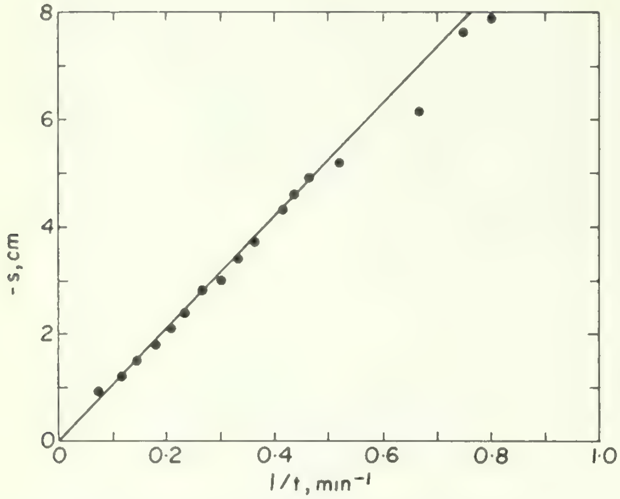


Figure 19. Response to a slug injection.

Again the pump discharge may require correction to determine an appropriate value for Q in tight aquifers.

Slug test analysis. — Three methods of slug test analysis as proposed by Papadopulos and others (1973), Cooper and others (1967), and by Hvorslov (1951), are treated in this section.

The method proposed by Papadopulos and others (1973) is as follows (adapted from McWhorter and Sunada 1977).

1. On rectangular coordinate paper plot the residual buildup of the water level due to a slug injection vs inverse time (fig. 19).

2. Select any arbitrary point on the curve of $-s$ vs l/t. The coordinate of the point ($-s$, l/t) is inserted into the following equation to determine T.

$$T = V/4\pi t(-s)$$

where:

v = slug volume

t = time

s = buildup due to the slug injection.

Example (McWhorter and Sunada 1977)

Determine the transmissivity from the following data.

$V = 0.148\ m^3$

-s(cm)	7.9	7.6	6.1	5.2	4.9
l/t(min^{-1})	0.800	0.750	0.667	0.521	0.461
-s 4.6	4.3	3.7	3.4	3.0	2.8
l/t 0.435	0.413	0.361	0.333	0.300	0.265
-s 2.4	2.1	1.8	1.5	1.2	0.9
l/t 0.231	0.212	0.183	0.146	0.117	0.077

These data are plotted on coordinate paper as shown in fig. 19. A point on the line is fig. 19 is selected arbitrarily; in this case the coordinates of the point are $-s = 6.3$ cm, l/t = 0.6. From the foregoing,

$$T = V/4\pi t(-s)$$
$$= 0.148/[4\pi(0.6)(6.3/100)$$
$$= 0.11\ m^2/min.$$

Note this method does not provide a reliable determination of the storage coefficient (Cooper and others 1967) and does not account for changes in well-bore storage.

The method of analysis as proposed by Cooper and others (1967) is as follows.

1. On semi-log paper plot H/H_o on the arithmetic axis vs time on logarithmic axis (field curve) where

H_o = the buildup of the water level at time t=0 due to a slug injection,

H = the residual water table buildup some time t after injection.

2. From table 21 prepare a semi-log plot of H/H_o vs Tt/r^2 (type curve), where r = radius of well casing, T = transmissivity, and t = time.

3. Superimpose the field curve on the type curve keeping the horizontal axes coincident. Adjust the position of the field curve so as to achieve the best fit of data to the type curves (see fig. 20).

4. Select an arbitrary "match" point and read the corresponding values of t (from the field curve) and Tt/r^2 (from the type curve).

5. Insert the corresponding match point values for t and Tt/r^2 into the following equation and solve for T.

Table 21. — Values of H/H_0 for a Well of Finite Diameter (from Cooper and others 1967).

Tt/r_c^2	H/H_0				
	$\alpha = 10^{-1}$	$\alpha = 10^{-2}$	$\alpha = 10^{-3}$	$\alpha = 10^{-4}$	$\alpha = 10^{-5}$
1.00×10^{-3}	0.9771	0.9920	0.9969	0.9985	0.9992
2.15×10^{-3}	0.9658	0.9876	0.9949	0.9974	0.9985
4.64×10^{-3}	0.9490	0.9807	0.9914	0.9954	0.9970
1.00×10^{-2}	0.9238	0.9693	0.9853	0.9915	0.9942
2.15×10^{-2}	0.8860	0.9505	0.9744	0.9841	0.9888
4.64×10^{-2}	0.8293	0.9187	0.9545	0.9701	0.9781
1.00×10^{-1}	0.7460	0.8655	0.9183	0.9434	0.9572
2.15×10^{-1}	0.6289	0.7782	0.8538	0.8935	0.9167
4.64×10^{-1}	0.4782	0.6436	0.7436	0.8031	0.8410
1.00×10^{0}	0.3117	0.4598	0.5729	0.6520	0.7080
2.15×10^{0}	0.1665	0.2597	0.3543	0.4364	0.5038
4.64×10^{0}	0.07415	0.1086	0.1554	0.2082	0.2620
7.00×10^{0}	0.04625	0.06204	0.08519	0.1161	0.1521
1.00×10^{1}	0.03065	0.03780	0.04821	0.06355	0.08378
1.40×10^{1}	0.02092	0.02414	0.02844	0.03492	0.04426
2.15×10^{1}	0.01297	0.01414	0.01545	0.01723	0.01999
3.00×10^{1}	0.009070	0.009615	0.01016	0.01083	0.01169
4.64×10^{1}	0.005711	0.005919	0.006111	0.006319	0.006554
7.00×10^{1}	0.003722	0.003809	0.003884	0.003962	0.004046
1.00×10^{2}	0.002577	0.002618	0.002653	0.002688	0.002725
2.15×10^{2}	0.001179	0.001187	0.001194	0.001201	0.001208

Table 22. — Rise of water level in Dawsonville well after simultaneous withdrawal of weighted float (r-7.6 cm) (from Cooper and others 1967).

t (sec)	1/t	Head (m)	H (m)	H/Ho
−1		0.896		
0		0.336	0.560	1.000
3	0.333	0.439	0.457	0.816
6	0.167	0.504	0.392	0.700
9	0.111	0.551	0.345	0.616
12	0.0833	0.588	0.308	0.550
15	0.0667	0.616	0.280	0.500
18	0.0556	0.644	0.252	0.450
21	0.0476	0.672	0.224	0.400
24	0.0417	0.691	0.205	0.366
27	0.0370	0.709	0.187	0.334
30	0.0333	0.728	0.168	0.300
33	0.0303	0.747	0.149	0.266
36	0.0278	0.756	0.140	0.250
39	0.0256	0.765	0.131	0.234
42	0.0238	0.784	0.112	0.200
45	0.0222	0.788	0.108	0.193
48	0.0208	0.803	0.093	0.166
51	0.0196	0.807	0.089	0.159
54	0.0185	0.814	0.082	0.146
57	0.0175	0.821	0.075	0.134
60	0.0167	0.825	0.071	0.127
63	0.0159	0.831	0.065	0.116

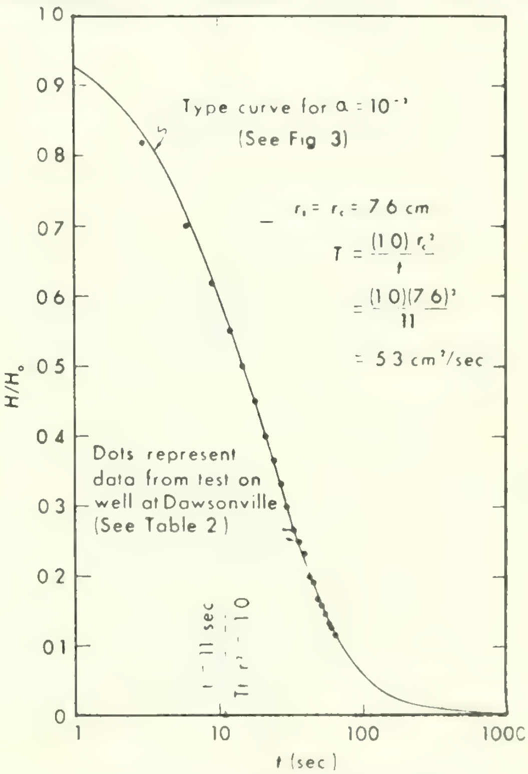


Figure 20. Plot of data from test at Dawsonville, Georgia, superposed on type curve (from Cooper and others 1967).

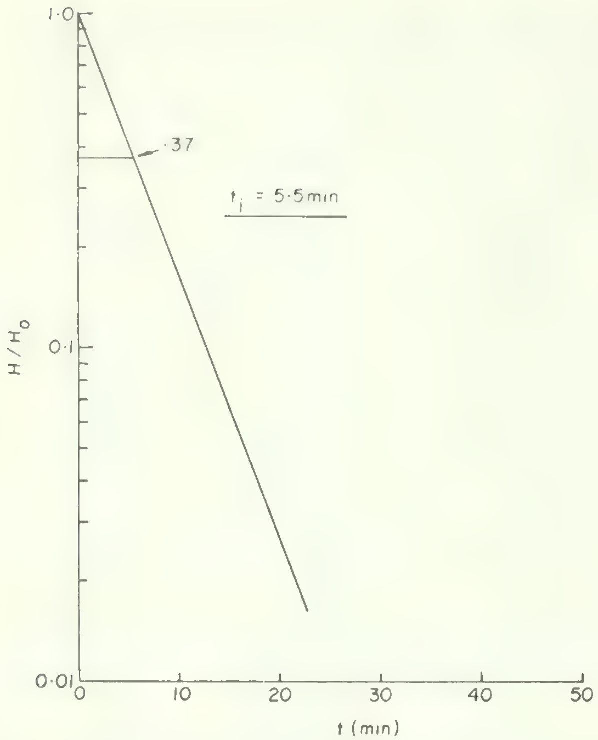


Figure 21. Time lag plot.

$$T = [(Tt/r^2)r^2]/t$$

where:

T = transmissivity

r = well casing radius

t = time coordinate on the field curve of the match point

Tt/r^2 = the value of Tt/r^2 on the type curve corresponding to the match point.

Example (Cooper and others 1967)

Given the test data listed in table 22, determine the transmissivity. A plot of H/H_o vs t superimposed on the type curve is shown in fig. 20. The coordinates of the match point are determined from fig. 20 to be Tt/r^2 = 1.0, t = 11 sec. From the foregoing,

$$T = [(Tt/r^2)r^2]/t = [1(7.6)^2]/11$$

$$= 5.3 \text{ cm}^2/\text{sec} = 5.3\text{x}10^{-4} \text{ m}^2/\text{min}.$$

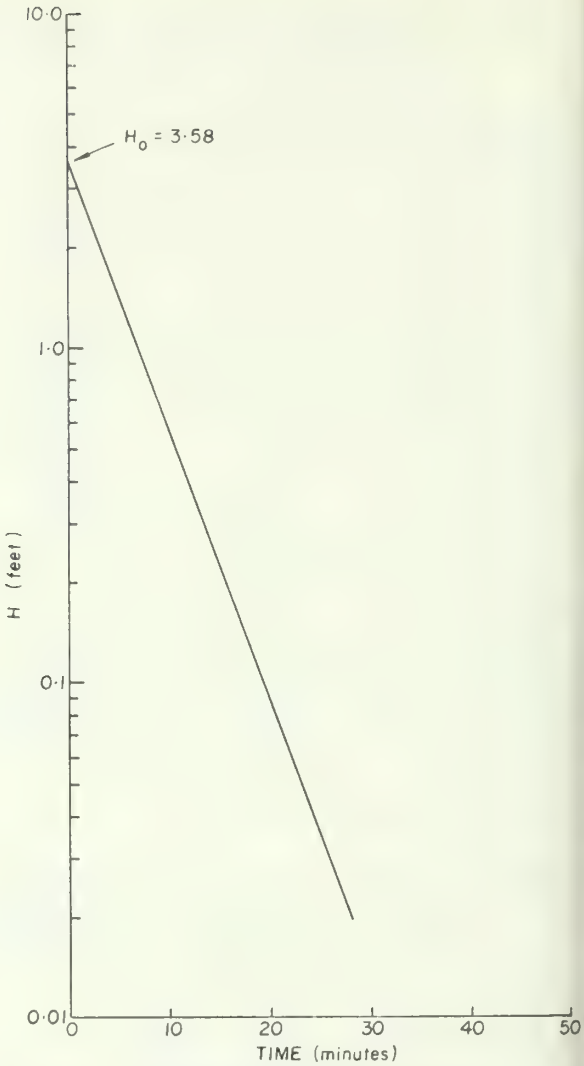
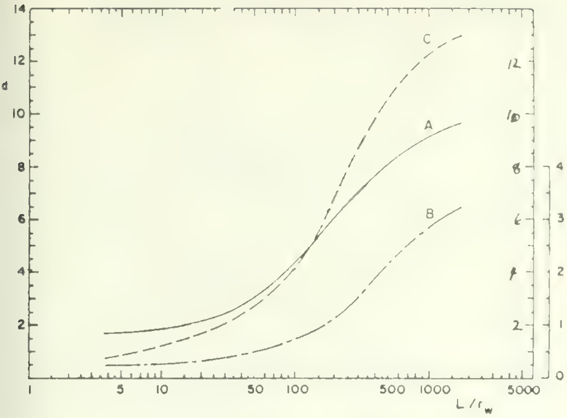


Figure 22. Plot the buildup H vs time.

Note: this method does not provide a reliable de termination of the storage coefficient, S (Coope and others 1967).

Slug test as proposed by Hvorslev (1951) i as follows:

1. On semi-log paper plot H/H_o on th logarithmic axis vs time on the arithmetic axis a shown in fig. 21. H_o, the buildup of water leve at time zero, is best determined as follows. Plo the buildup H vs time on semi-log paper as il lustrated in fig. 22. Extrapolate the straight lin position of the plot to time t=0 to determine H_o the initial buildup due to a slug injection at tim zero. Once H_o is determined, values of H/H_o ca be calculated and plotted as in fig. 21.



gure 23. **Curves relating coefficients A, B, and to L/r_w.**

2. From the semi-log plot of H/H_o vs t, termine the coordinates of t_L, the time lag, rresponding to $H/H_o = 0.37$ (fig. 21).

3. Determine the coefficient C (fig. 23) rresponding to value of L/r_w derived from the ll construction data where L = screen length, = well radius or radius of well plus the gravel ck.

4. Insert the coefficient C into the folving equation to determine $1n\ R_e/r_w$.

$$\ln R_e/r_w = \left[\frac{1.1}{\ln H_w/r_w} + \frac{C}{L/r_w} \right]^{-1}$$ (Bouwer and Rice 1976)

ere R_e = the effective radius of buildup, r_w well radius or radius of well and aquifer pack known), L = screen length, and H_w = distance tween the bottom of the well and the static ound water surface (see fig. 24 for the relation tween H_w, r_w, L).

5. Insert the values of time lag (t_L), 1n R_e/r_w, and the well casing diameter into the folving equation to determine K (for completely netrating well).

$$K = \frac{d^2 \ln R_e/r_w}{8Lt}$$ (Hvorslev 1951)

ere:

d = well casing diameter

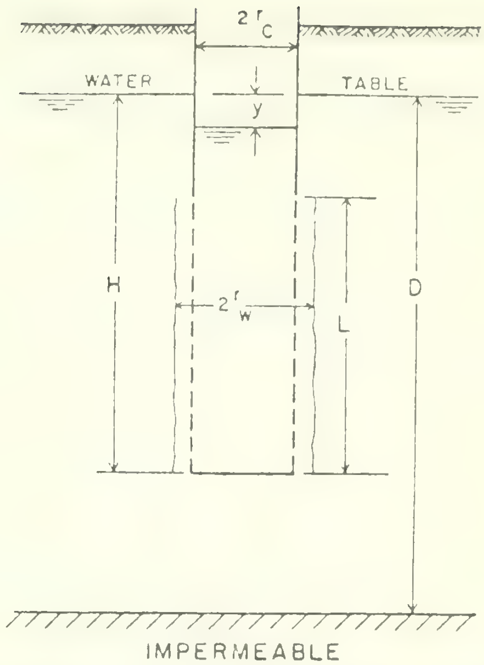


Figure 24. Geometry and symbols of a partially penetrating, partially perforated well in unconfined aquifer with gravel pack or developed zone around perforated section.

$1n\ R_e/r_w$ = described in steps 3 and 4

L = screen length

t = time

K = hydraulic conductivity.

Example

Given the following well construction and slug test data, determine the hydraulic conductivity.

d = 0.42 ft, L = 20 ft, r_w = 0.21 ft,

H_w = 94.08 ft.

H(feet)	3.27	2.94	2.44	2.01	1.68	1.39
t(min)	0.5	1.0	2.0	3.0	4.0	5.0

H	1.24	0.96	0.81	0.68	0.56	0.38	0.26
t	6.0	7.0	8.0	9.0	10.0	12.0	14.0

H	0.18	0.12	0.08	0.05	0.03	0.02	0.01
t	16.0	18.0	20.0	25.0	26.0	30.0	40.0

A plot of H vs t is shown in fig. 22. H_o is determined by extrapolating the straight portion of this plot to time t=0. From fig. 22 H_o = 3.58 ft.

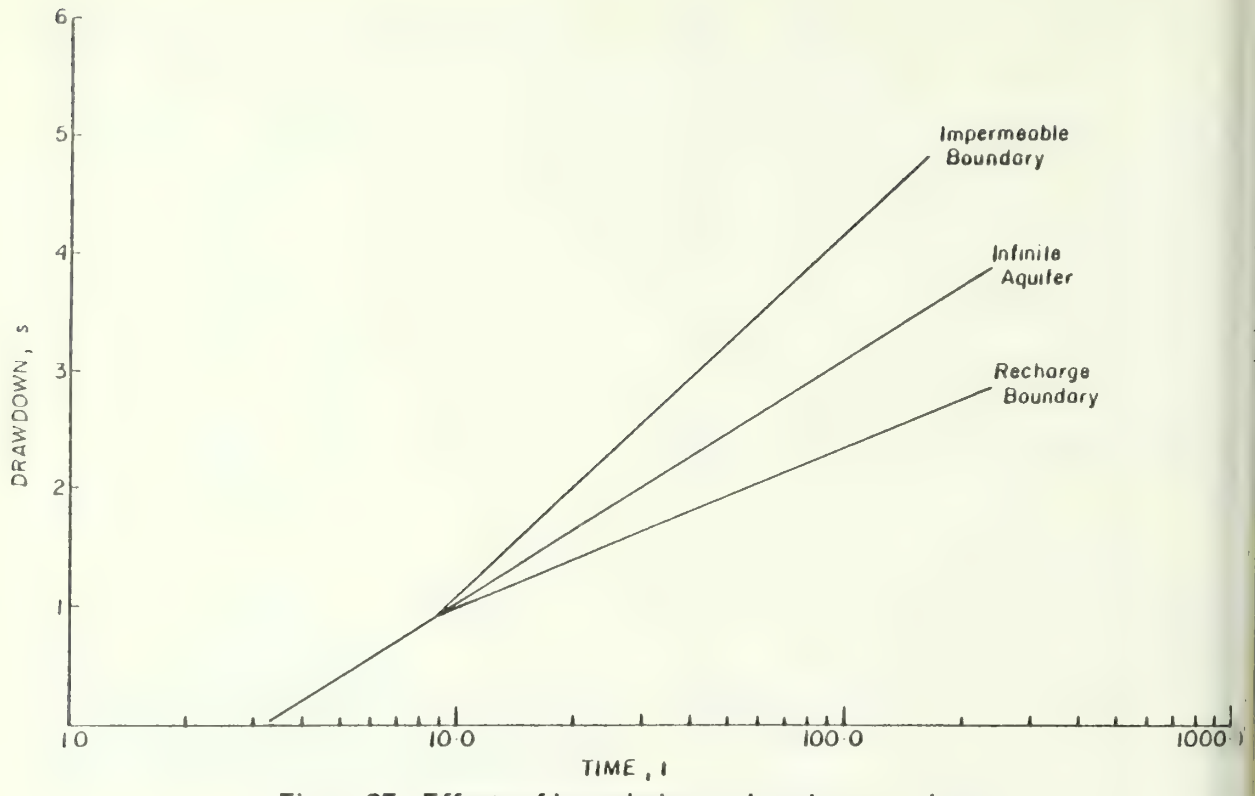


Figure 25. Effects of boundaries on drawdown vs time.

The time lag t_L is 5.5 min as shown in fig. 21. From fig. 22 the value of C corresponding to $L/r_w = 95.2$ is $\simeq 4.25$. From before

$$\ln R_e/r_w = \left[\frac{1.1}{\ln H_w/r_w} + \frac{C}{L/r_w}\right]^{-1}$$

$$= \left[\frac{1.1}{\ln 94.08/0.21} + \frac{4.25}{20/0.21}\right]^{-1}$$

$$= 4.45.$$

Therefore, the hydraulic conductivity is

$$K = [d^2 \ln R_e/r_w]/8Lt_L$$

$$= [(0.42)^2\,(4.45)]/[8(20)(5.25)]$$

$$= 9.35 \text{ ft/min} = 1.35 \text{ ft/day}.$$

Note: $T = K{\cdot}b$ where T = transmissivity, K = hydraulic conductivity, and b = aquifer thickness. If the aquifer thickness is the same as the screen length (L=20 ft), then the transmissivity is

$$T = K \cdot b = (1.35)(20) = 26.9 \text{ ft}^2\text{/day}.$$

EFFECTS OF BOUNDARY CONDITIONS AND WELL CONSTRUCTION ON AQUIFER TEST RESULTS

Aquifer boundary conditions are ra known at the field site prior to conducting aquifer test. Any boundary effects must recognized by the field investigator in orde avoid serious errors in the calculation of aquifer parameters. Figures 25 and 26 illust the effect of recharge and impervious boun conditions on the time-drawdown and dista drawdown curves, respectively. The effect these boundary conditions are summarize table 23 (Johnson, Inc. 1974, p. 132). Recha boundary effects may be caused by nearby r or lakes, vertical infiltration from overl zones, and increases in aquifer thickness or draulic conductivity. Impermeable boundar fects may be caused by geologic fault zones crease in aquifer thickness (pinch out), dec in hydraulic conductivity, and impermeable

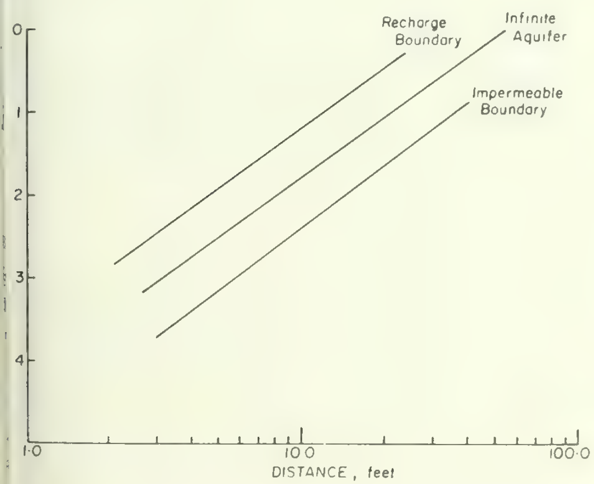
Table 23. — Comparisons of recharge and boundary effects on semilog diagrams

Recharge effect during pumping test

Time-drawdown graph	Distance-drawdown graph
1. Slope of graph becomes flatter. If transmissibility is calculated on the basis of the flatter slope it will be higher than the true value.	1. Slope of straight line remains almost unchanged. Aquifer transmissibility calculated from the graph is usually close to its true value.
2. Extending straight line of flatter slope results in an erroneous value of t_0 making it too low. A calculation using this figure gives a value for the storage coefficient that is smaller than the correct one.	2. Straight line is displaced upward. Extension to zero drawdown gives a value of r_0 which when used to compute storage coefficient results in a value higher than the correct one.

Boundary effect during pumping test

Time-drawdown graph	Distance-drawdown graph
1. Slope of graph becomes steeper. If transmissibility is calculated on the basis of the steeper slope it will be lower than the true value.	1. Slope of straight line remains almost unchanged. Aquifer transmissibility calculated from the graph is usually close to its true value.
2. Extending line of steeper slope results in erroneous value of t_0 which is too high. A calculation using this figure gives a storage coefficient that is larger than its correct value.	2. Straight line is displaced downward. Extension to zero drawdown gives erroneous value of r_0 which makes calculated value of storage coefficient smaller than the correct one.



igure 26. Effects of boundaries on drawdown distance.

ck. If boundary effects are apparent during e aquifer test, then the aquifer parameters ust be determined from test data collected ior to the time the boundary effects are ob-vable in the data.

Proper well construction is critically important if the aquifer test is to provide data representative of the aquifer. The following well design and construction factors contribute to excessive drawdown during the aquifer test (Johnson, Inc. 1974):

1. Well screens with insufficient open area.
2. Poor distribution of well screens.
3. Insufficient well screen length.
4. Inadequate well development.
5. Improper placement of the well screen.

Any one of these factors can significantly reduce the calculated values of transmissivity or hydraulic conductivity.

Example

Once the hydraulic coefficients are known, they can be used to estimate mine inflow and the extent to which the piezometric surface is disturbed. There are a variety of ways in which this can be accomplished that range from simple idealizations to application of sophisticated

Table 24. — Example of lateral inflow computation

Time	q	Q_1	Q_2	Q_3	Q_4	Q_5	Q_{total}
Years	$ft^3/ft\text{-}d$	ft^3/d					
.25	2.8	4200	–	–	–	–	4200
.50	2.0	3000	4200	–	–	–	7200
.75	1.6	2400	3000	4200	–	–	9600
1.00	1.4	2100	2400	3000	4200	–	11700
1.25	1.3	1950	2100	2400	3000	4200	13650
1.50	1.2	1800	1950	2100	2400	3000	11250
1.75	1.1	1650	1800	1950	2100	2400	9900
2.00	1.0	1500	1650	1800	1950	2100	9000
2.25	0.95	1425	1500	1650	1800	1950	8325

models. The following is an example when the relatively simple idealization of one-dimensional inflow to a pit is applicable.

The inflow to a mine pit that cuts through an aquifer is given by

$$q = 2(12t/S_{ya}Th_o^2)^{-1/2} + q_o \quad ,$$

where:

- q = inflow discharge per unit of pit length (both sides)
- q_o = natural flow in undisturbed aquifer per unit of pit length
- t = time since inflow began
- S_{ya} = apparent specific yield
- T = transmissivity
- h_o = initial saturated thickness of aquifer.

This equation is a special case of a more general result given by Bear (1972). The discharge predicted by this equation is the inflow discharge per unit of open pit. A mining plan is required to convert these values into actual discharges to be expected at any time. For example, suppose S_{ya} = 0.05, T = 10 ft^2/day, h_o = 65 ft, q_o = 0, and the mining plan calls for 1,500 ft of pit to be open every 3 months until a total pit length of 7,500 ft is achieved and the pit length is constant thereafter. Pit inflow as a function of time is computed by calculating the inflow from each segment of the pit, marking time for each segment from the time that the segment was opened. The contributions from each segment at any time after the opening of the first segment are calculated by adding the contributions from each individual section. The computations are summarized in table 24. Q in this table is the discharge per unit of pit length (q) multiplied by the length of the open segment. The subscripts refer to the first, second, etc., segments of the pit. Q_{total} represents the inflow from the total length of open pit at any time. The maximum inflow discharge is 13,650 ft^3/day or about 70 gal/min in this example.

The theory leading to the above equation also provides a means for estimating the distance from the pit to points where the piezometric surface remains essentially undisturbed. The equation is

$$L = (3Tt/S_{ya})^{1/2}$$

where L is the distance from the pit to the point where the drawdown of the piezometric surface is zero. Using the same numbers for T and S_{ya} as above, this equation predicts that inflow to the pit will cause the piezometric surface to be depressed to a distance of about 0.5 miles from the pit after 20 years.

The above equations and computations are presented to demonstrate one possible use of the hydraulic coefficients. Other uses exist and, certainly, there are many other ways to estimate pit inflow during mining. The above constitutes an example, not a recommendation.

Effect of Abandoned Mine on Piezometric Surface. — Another aspect that is sometimes im-

portant in premine planning and decision making is the extent to which the original piezometric surface will remain disturbed after the mine is abandoned. McWhorter and Rowe (1976) and Hamilton and Wilson (1977) provide approaches to this problem. McWhorter and Rowe (1976) idealize the abandoned mine area as a circle of radius R and area equal to the actual mined area. Their equation for the distance to which the postmining piezometric head is different from the premining value by an arbitrary amount is

$$r = \frac{R}{\sqrt{c}} \left(\left| \frac{K_o - K_i}{K_o + K_i} \right| \right)^{1/2}$$

where:

- r = distance from the center of the mined area to points where postmining piezometric head is different from the premining value by an arbitrarily small fraction equal to c.
- R = equivalent radius of the mined area.
- c = ratio of the difference between premining and postmining values of piezometric head to the premining value.
- K_o = hydraulic conductivity outside the mined area.
- K_i = hydraulic conductivity inside the mined area.

Use of the above equation requires that both K_o and K_i are known. Prior to mining, K_i is not known. Nevertheless, the maximum distance can be estimated by putting $K_i=0$ or $K_i = \infty$ for which

$$r = R\sqrt{c}$$

For example, the distance to which the postmining piezometric head differs from the premining value by 10 percent if $r = R/\sqrt{0.10} = 3R$.

The analysis also permits one to establish other limiting values that may be of interest. For example, it is shown that the maximum width of the downstream plume of ground water of modified quality is 4R. Also, postmining flow through the mined area can be no greater than twice the premining flow through the same area, regardless of how permeable the spoils are compared to the undisturbed aquifer.

The conditions under which the foregoing analyses are made are highly idealized relative to the conditions that can be expected to prevail in the field. The results should be expected to yield only order-or-magnitude estimates of the extent to which the long-term, postmining ground water flow differs from the premining condition. Hamilton and Wilson (1977) provide results similar to those discussed above for a variety of mine geometries.

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APPENDIX I

SOURCES OF GEOLOGICAL, HYDROLOGICAL, SOIL AND RECLAMATION DATA

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Economic Geology.
Geology of ore deposits (abstracts of Russian Academy of Science articles) in several issues ea year.

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1971. Surface mined areas. Control and reclamation of environmental damage. A bibliograph USDI Office of Library Services, Bibliography Series 27.

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University of East Anglia, Norwich, England.
With a worldwide geographical and subject index in seven parts:
A. Landforms and the quaternary
B. Climatology and hydrology
C. Economic geography (including minerals)
D. Social and historical geography
E. Sedimentology
F. Regional and community planning
G. Remote sensing and cartography.

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APPENDIX II

UNITED STATES — STATE GEOLOGICAL SURVEYS AND BUREAUS OF MINES FOR THE ROCKY MOUNTAIN REGION

Arizona Bureau of Mines
Univ. of Arizona
Tucson, Ariz. 85721

Colorado Geological Survey
1845 Sherman St.
Room 254
Denver, Colo. 80203

Idaho Bureau of Mines and Geology
Univ. of Idaho
Moscow, Idaho 83843

Montana Bureau of Mines and Geology
Montana College of Mineral Science and Technology
Butte, Mont. 59701

New Mexico Bureau of Mines and Mineral Resources
Socorro, N.M. 87801

North Dakota Geological Survey
Univ. Station
Grand Forks, N.D. 58202

South Dakota Geological Survey
Science Center
Univ. of South Dakota
Vermillion, S.D. 57069

Utah Geological and Mineral Survey
103 UGS Bldg.
Univ. of Utah
Salt Lake City, Utah 84112

Geological Survey of Wyoming
Box 3008, Univ. Station
Univ. of Wyoming
Laramie, Wyo. 82071

APPENDIX III

CODES FOR ABBREVIATIONS AND SYMBOLS USED IN CONSTRUCTION OF LITHOLOGIC LOG (FIGURE 5 IN TEXT)

BEDDING THICKNESS

H	-	Homogeneous (no lamination)
H - DM		Homogeneous, distinctly mottled
H - IM		Homogeneous, indistinctly mottled
L	-	Laminated - < 1 cm thick
F	-	Thin bedded - 1-10 cm thick
M	-	Medium bedded - 10-30 cm thick
T	-	Thick bedded - 30-100 cm thick
VT	-	Very thick bedded - > 100 cm thick
L/F	-	Thin bedded sets of cross-lamination, etc.

INDURATION

U	-	Unconsolidated
I	-	Indurated
IP	-	Indurated but plastic
IS	-	Indurated but shaly
IF	-	Indurated but friable
WI	-	Well indurated

SORTING

WS	-	Well sorted
MWS	-	Moderately well sorted
MS	-	Moderately sorted
PS	-	Poorly sorted

ROUNDNESS

A	-	Angular
S	-	Sub-rounded to sub-angular
R	-	Rounded

PERCENT LIMESTONE (SCALE OF 1-10)

< 1	Trace of effervescence
1	Slight effervescence
3	Moderate effervescence
5	Strong effervescence
10	Very strong effervescence
> 10	Limestone

SAMPLE TYPE

T.S.	-	Thin section sample
S	-	Size sample
X	-	X-ray analysis sample
G	-	Growth study sample

ROCK TYPE AND ACCESSORY SYMBOLS

(see chart A p. 104)

SEDIMENTARY STRUCTURE SYMBOLS

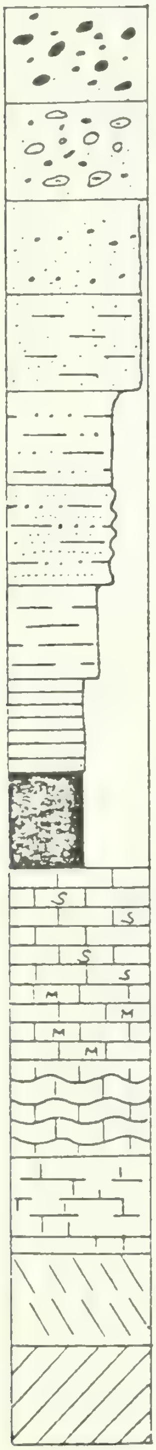
(see chart B p. 105)

DESCRIPTION

Color, size, sorting, rock type, Sedimentary Structure,
Example: red, fine-grained, well sorted, sandstone, with horizontal laminations.

CHART A

ROCK TYPE SYMBOLS



- conglomerate
- intraclastic conglomerate
- sandstone (with granule layers)
- clayey sandstone
- siltstone
- sandstone and siltstone
- mudstone
- claystone
- coal or peat
- limestone (sparry)
- micritic limestone
- algal limestone
- marlstone (clayey limestone)
- gypsum
- lost core

ACCESSORY SYMBOLS

- calcareous (>3%)
- marcasite nodules
- pyrite nodule
- oxydized pyrite nodule
- plant fragments and carbonaceous mat
- pelletoids
- limonitic nodules
- gypsum
- organic partings
- clay gall intraclasts
- nodules
- glauconite
- megafossils
- mica
- chert
- oxydized colors (reddish)
- bentonite
- feldspar
- clayey
- iron oxide nodules
- manganese

CHART B

SEDIMENTARY STRUCTURE SYMBOLS

"structureless" sand

interbedded sand and granule layers (horizontal bedding)

large scale cross-bedding (tabular)

low angle cross-bedding

parallel bedding

trough cross-bedding

scours (with channel lag)

scour and fill

downcutting surface

ripple-tabular x-lamination

ripple-trough cross-lamination

ripples in — drift

ripples on crossbeds

wavey bedding

coarsely interlayered sand and mud

alternating sand and mud

flaser bedding

wavey bedding

lenticular bedding

weak

moderate — Bioturbation

strong

rooting

microfaults

contorted (slumped) beds

growth faults

bimedal current directions

loadcasting

mudcracks

forset beds

APPENDIX IV

MANUFACTURERS AND DISTRIBUTORS

Listing of manufacturers and distributors who have been referred to in this report.

Acker Drill Company
P. O. Box 830
Scranton, Penn. 18501

Boyle Bros.
P. O. Box 25068
1624 Pioneer Road
Salt Lake City, Utah 84125

Christensen Mining Products Division
Christensen Diamond Products Company
1937 South 300 West
Salt Lake City, Utah 84115

Joy Manufacturing Company
Montgomery Industrial Center
Montgomeryville, Penn. 18936

Longyear Company
925 Delaware Street, S.E.
Minneapolis, Minn. 55414

Mobile Drilling Company, Inc.
3807 Madison Avenue
Indianapolis, Ind. 46227

Odgers Drilling, Inc.
Ice Lake Road
Iron River, Mich. 49935

Penndrill Manufacturing Division
Pennsylvania Drilling Company
P.O. Box 8562
Pittsburgh, Penn. 15220

Pitcher Drilling Company
75 Allemany Street
Daly City, Calif. 94014

Reed Tool Company
105 Allen Street
P. O. Box 3641
San Angelo, Texas 76901

Reese Sales Company
P. O. Box 645
2301 Gibson Street
Bakersfield, Calif. 93302

Soiltest, Inc.
2205 Lee Street
Evanston, Ill. 60202

Sprague and Henwood, Inc.
221 West Olive Street
Scranton, Penn. 18501

Triefus Industries (W.A.) Co.
Sidney, Australia

☆ U.S. GOVERNMENT PRINTING OFFICE: 1979-0-677-121/91

Barrett, James, Paul C. Deutsch, Frank G. Ethridge, William T. Franklin, Robert D. Heil, David B. McWhorter, Alv D. Youngberg

1979. Procedures recommended for overburden and hydrologic studies of surface mines. USDA For. Serv. Gen. Tech. Rep. INT-71, 106p Intermt. For. and Range Exp. Stn., Ogden, UT 84401.

Presents information on gathering and analyzing data regarding overburden and hydrologic studies of surface mines.

KEY WORDS: Hydrology, soils, overburden, core drilling, surface mining.

THE SEAM PROGRAM

The Surface Environment and Mining Program, known as SEAM, was established by the Forest Service to research, develop, and apply new technology to help maintain a quality environment while helping meet the Nation's mineral requirements. SEAM is a partnership of researchers, land managers, mining industries, universities, and political jurisdictions at all levels.

Although the SEAM Program was assigned to the Intermountain Station, some of its research projects were administered by the Rocky Mountain and Pacific Southwest Research Stations.

ROADLESS AREA — INTENSIVE MANAGEMENT TRADE-OFFS ON THE BRIDGER-TETON AND LOLO NATIONAL FORESTS

Enoch F. Bell
K. Norman Johnson
Kent P. Connaughton
Robert W. Sassaman

USDA Forest Service General Technical Report INT-72
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service, U.S. Department of Agriculture

USDA Forest Service
General Technical Report INT-72
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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
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KENT P. CONNAUGHTON and ROBERT W. SASSAMAN are economists, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

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RESEARCH SUMMARY

It has been suggested that the capital outlay associated with roading roadless areas for timber management be reallocated to intensive timber culture on areas already accessible in the National Forest System. As a part of a westwide effort, the Bridger-Teton and Lolo National Forest were studied to determine the consequences of such actions in terms of harvest, financial, employment, environmental and multiple-use effects.

Results indicate that when all roadless areas are removed from the timber harvest base and funds for intensive management are provided, the Lolo can make up one quarter of the 66 million board foot annual loss in timber harvest. Furthermore, the lowest level of harvest is above the past 5-year average sell; so actual harvest effects could be nil. The Bridger-Teton National Forest, however, can not make up any of its 25 million board foot annual loss.

Gross revenue, net revenue, costs, county payments, present net worth, and employment may decline on both forests when all or half of the roadless areas are withdrawn from the timber management base. On the Lolo, removal of all roadless areas would reduce the present net worth by $14.8 million and the employment by 980 man-years. Removal of the roadless areas on the Bridger-Teton National Forest would reduce present net worth and employment by $7 million and 400 man-years.

Some major environmental and multiple-use trade-offs will occur if the roadless areas are removed from the timber harvest base. On the Lolo National Forest, water quality, soil stability, and wildlife populations would benefit in the roadless areas. Forage production and wildlife populations would benefit in the accessible areas at the expense of forage production in the roadless areas. On the Bridger-Teton National Forest, water quality, fish, and wildlife populations away from roads would benefit at the expense of road-related dispersed recreation and mineral and energy development.

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INTRODUCTION

Increasing demands on our limited resource base have caused increasing conflicts over the management of public lands. One area of heated debate has been the question of whether to develop the roadless lands on national forests or place them in the wilderness system. One portion of the public points out our need for benefits such as wood products, motorized access, and developed recreation sites, which can only be achieved by development. Another portion of the public cites the increasing need for the decreasing areas available for undeveloped recreation, peace of mind, and research.

In 1977, Kurt Kutay, land use consultant, proposed an alternative in the Oregon economic impact assessment of proposed wilderness legislation that he claimed would benefit both publics and thus form a basis for consensus. He proposed that it might be possible to produce the timber required and also keep the roadless areas for wilderness or other use by shifting the funds that would be used to construct roads in the roadless areas to intensive timber management on the areas already roaded.

To test the feasibility of this proposal and to show its consequences, a study team of Forest Service economists and planning personnel was organized. This team selected seven western national forests in five regions for detailed study (fig. 1). For each forest, the test was made using existing Forest Service policies, procedures, and data. A summary of the results from that study has been published (Fight and others 1978).

The purpose of the present report is to detail study procedures and results for the two test forests in the Forest Service's Northern and Intermountain Regions. Specifically, this report covers the Lolo and Bridger-Teton National Forests. Originally, the Payette and the Nezperce National Forests were also included, but lack of adequate intensive management yield tables and time caused us to drop them. Some initial trials on the Nezperce showed a 56 percent reduction in programed harvest from removing all of the 428,000 commercial forest acres (173 000 ha) in roadless areas from the timber harvest base. Subsequent changes in constraints and acres have modified these results.

An overview of the two forests studied will be presented, overall methodology will be discussed, and physical, environmental, and economic effects will be presented.

DESCRIPTION OF THE SELECTED FORESTS

The Bridger-Teton and Lolo National Forests were selected for the study based on a number of criteria. First, timber data for the timber harvest scheduling model had to be available. This restricted the selection to only a few forests in both Regions. Second, the forest should have at least a moderate proportion of their commercial forest land in roadless areas. Finally, road costs, land productivity, and multiple-use constraints should be average for the Regions represented. The Lolo National Forest met these considerations and although the Bridger-Teton did meet most of the considerations it was chosen more for the fact that it represented an extreme case in terms of amount of forest land in the roadless category.

Figure 1.--Map of study forests.

Bridger-Teton National Forest

The Bridger-Teton National Forest is in the Rocky Mountains of northwestern Wyoming. Most of the forest is found in Teton, Sublette, and Lincoln Counties bordering Grand Teton and Yellowstone National Parks. As is shown in table 1, the Bridger-Teton contains about 1 million acres of regulated commercial forest land. This represents only 31 percent of the total forest acreage. Wilderness presently accounts for 28 percent of the forest. That acreage along with 1.75 million acres (708 000 ha) set aside from roadbuilding and development by the Forest Service's Roadless Area Review and Evaluation (RARE II) covers 79 percent of the forest.

Table 1.--*National forest land areas by use*

Item	Lolo acreage (1000's)	Bridger-Teton acreage (1000's)
	- - - - - - *Acres* - - - - - - (*Hectares*)	
Total national forest	2,091 (846)	3,400 (1 376)
National forest acres in wilderness	110 (44)	949 (384)
National forest acres in roadless areas	[1]758 (307)	1,750 (708)
Regulated commercial forest land (CFL)[2]	1,500 (607)	1,067 (432)
Regulated CFL in roadless areas	430 (174)	734 (297)

[1]Not equal to the 682,000 acres (276 000 ha) in RARE II on the Lolo because of changes that occurred after the data was gathered.

[2]That portion of the commercial forest land included in the land base for timber harvest calculations. The proposed timber management plan for the Bridger-Teton National Forest, which was completed after the study, reports 957,000 acres (387 000 ha) in regulated CFL.

Because of its location and size the Bridger-Teton National Forest receives considerable recreation and grazing use. However, the 7,576 MM bd.ft. regulated timber inventory has produced an average annual sell over the past 3 years of 31 MM bd.ft. The inventory is primarily composed of lodgepole and whitebark pines, Engleman spruce, subalpine fir, and Douglas-fir. The key game animals are elk, deer, antelope, moose, bighorn sheep, and grouse. Numerous trout species are extensively fished. In fact, this forest has the largest elk and moose populations of any national forest. Approximately 1.7 million visitor days of recreation are produced on the forest of which 19 percent are related directly to hunting and fishing. Range production accounts for 256,000 animal unit months annually.

A comparison with other forests in the Intermountain Region shown in table 2 indicates the Bridger-Teton's dominant position in a number of respects. Not only is the largest forest, but also it has the largest wilderness area and the largest roadle area inventory in the Region. The largest wilderness is probably one reason why it ranks fourth in terms of recreation visitor days in spite of its remoteness from major population centers. Its proximity to Grand Teton and Yellowstone National Parks also affects recreation usage. Out of 16 forests, the Bridger-Teton ranks fifth in terms of timber production.

Table 2.--*Comparison of selected items for national forests in the Intermountain Regio*

National forest	Net national forest acreage[1] (1000's)	Percent of net acres in wilderness and roadless areas	Timber sold 1977	Recreation visitor-days 1977 (1000's)	Authorized forage use 1977 (1000's)
	Acres (Hectares)	*Percent*	*MM bd.ft.*		*Aum's*[2]
Ashley	1,384 (560)	38	18	1,221	85
Boise	2,644 (1 070)	19	85	1,477	99
Bridger-Teton	3,400 (1 376)	79	35	1,690	256
Caribou	1,135 (459)	71	9	417	186
Challis	2,463 (997)	64	5	399	123
Dixie	1,884 (762)	18	27	1,458	113
Fishlake	1,424 (576)	41	3	1,164	153
Humboldt	2,528 (1 023)	63	Trace	483	324
Manti-Lasal	1,265 (512)	46	4	903	174
Payette	2,314 (936)	67	56	497	90
Salmon	1,770 (716)	56	38	400	51
Sawtooth	1,800 (728)	41	29	1,602	194
Targhee	1,642 (664)	61	82	1,720	162
Toiyabe	3,156 (1 277)	28	2	2,651	107
Uinta	813 (329)	57	3	1,532	124
Wasatch	1,419 (574)	49	7	5,031	85
TOTAL	31,042 (12 562)	50	402	23,515	2,327

[1]As of September 30, 1977.
[2]Animal unit months.

Lolo National Forest

The Lolo National Forest is located in west central Montana west of the Continental Divide. The major parts of the forest occur in Missoula and Mineral Counties with the city of Missoula being the closest major population center. As is shown in table 1, the forest contains about 1.5 million acres (607 000 ha) of commercial forest land regulated for timber harvest or about 72 percent of the forest acreage. One hundred ten thousand acres (44 517 ha) are presently dedicated to wilderness, while another 682,000 acres (276 000 ha) are included in RARE II as roadless. An additional 76,000 acres (31 000 ha) were classified as roadless that were removed from RARE II because of wilderness designation (Welcome Creek) and approved land management plans.

The Lolo has abundant resources that have considerable use. The 10 billion board feet of regulated timber inventory has produced an average annual sell of 90 million board feet over the last 5 years. Approximately 1.5 million visitor days of recreation are spent on the forest each year with hunting and fishing making up 17 percent of this use. The key game and fish species are elk, deer, bear, grouse, trout, and whitefish. The grizzly bear, peregrine falcon, and the Rocky Mountain wolf have been identified as rare or endangered species found on this forest. The Lolo also supplies 8,600 animal unit months of forage and water supplies for a number of towns, the city of Missoula, and local irrigation.

In relation to the 12 other forests in the Northern Region of the Forest Service (table 3), the Lolo National Forest is slightly above average in acreage, timber harvest, and road costs and much above average in recreation. It is the fifth largest forest and ranks fifth in terms of timber production. The Lolo ranks sixth for road costs and second in recreation visitor days. Its percent of area in wilderness and roadless areas, however, is below average, 38 percent, the fifth lowest forest.

Table 3.--Comparison of selected items for national forests in the Northern Region.

National forest	Net national forest acreage[1] (1000's)	Percent of net acres in wilderness and roadless areas	1977 timber sold	1976 road costs	1978 recreation visitor-days (1000's)
	Acres (Hectares)		*MM bd.ft.*	*$/M bd.ft.*	
Beaverhead	2,120 (858)	35	12		413
Bitterroot	1,576 (638)	72	44	54	428
Clearwater	1,677 (679)	65	160	29	868
Custer	1,188 (481)	50	1	93	679
Deerlodge	1,195 (484)	37	16	55	737
Flathead	2,365 (957)	60	121	29	854
Gallatin	1,734 (702)	65	7	43	1,930
Helena	972 (393)	64	6	108	233
Idaho Panhandle	3,213 (1 300)	25	254	34	1,334
Kootenai	1,826 (739)	20	197	38	423
Lewis & Clark	1,835 (743)	78	7	29	815
Lolo	2,091 (846)	38	109	45	1,476
Nezperce	2,206 (893)	70	77	37	832
TOTAL	23,998 (9 712)	50	1,011	36	11,021

[1]As of September 30, 1977.

With these points in mind regarding the characteristics of the forests it might be attractive to extrapolate the results of this study to the respective Regions. Experience with other forests in other regions has not revealed any procedures for consistently generalizing the results. Each forest has unique constraints ranging from environmental restrictions to timber sale budgets that vary by harvest level. Therefore, though the conclusions reported here apply to the forests studied, they do not necessarily apply to other forests in their regions.

STUDY ALTERNATIVES

To determine the effects of roadless area withdrawals and the opportunities for intensive timber management, five alternatives were examined for each forest (table 4) For each alternative both the programed harvest and the potential yield for timber were calculated. Potential yield in this study represents the expected annual timber harvest from all regulated commercial forest lands under full funding for intensive timber management subject to some multiple-use constraints. Programed harvest is that part of the potential yield that is funded for harvest in any given year. In this study, unregulated harvest and mortality salvage were not included in the results that are reported.

Table 4.--*Summary of alternatives*

Alternative	Roadless areas available for timber management	Funds reallocated to more intensive timber management	Harvest calculations: Programed harvest	Harvest calculations: Potential Yield	
Base	All	No	X	X	
50 percent out	Half	No	X	X	same
50 percent out--reallocation	Half	Yes	X	X	same
100 percent out	No areas available	No	X	X	same
100 percent out--reallocation	No areas available	Yes	X	X	same

The Base Alternative

The base alternative is used as a basis for comparison with the other alternatives. It represents a timber management plan in which all specified roadless areas are roaded and harvested. This alternative incorporates current plans for timber management, road construction, multiple-use constraints, and budget levels.

The acreage used in the base alternative includes the standard, special, and marginal components of the regulated forest base for potential yield calculations. These components amounted to 1,500,000 and 1,067,000 acres (607 000 and 432 000 ha) on the Lolo and Bridger-Teton, respectively; however, for the programed harvest calculation on the Bridger-Teton, the acreage was reduced to 462,000 acres (187 000 ha).

This reduction represents removal of the marginal acres that could not be managed in the next decade because of environmental, economic, and access constraints. The acreage did not change on the Lolo for the programed harvest calculation.

For both forests, management of these acres consisted of stocking the nonstocked backlog, reforestation, stocking level control where appropriate, thinning, and final harvest. The final harvest was programed for clearcut, shelterwood, and selection harvests, whichever is appropriate to meet the silvicultural and multiple-use objectives of the forest. Such intensive management practices as using genetically improved stock, fertilizing, and irrigation were not considered because either the results were not well established or the practice was not economically feasible. On the Lolo National Forest, some thinning of existing stands was not planned because of an anticipated lack of funds. The Bridger-Teton management intensity was not restricted by the anticipated budget because environmental concerns were more constraining.

Road requirements for the roadless areas were carefully evaluated for each forest by the forest engineers. On the Bridger-Teton, 1,185 miles (1 907 km) of roads were planned, but on the Lolo 2,931 miles (4 716 km) of roads were planned. Both forests were also asked to say how many additional roads would be needed on the roaded areas if the roadless areas were removed from the harvest base. The forests reported that no additional roads were needed beyond those already required for harvest of the roaded areas.

Both multiple-use and environmental constraints were carefully considered on both forests. These constraints usually resulted in reductions in harvest through reduced yields per acre, restricted access, and general limits on acres to be harvested. In some cases, these constraints dictated the kind of harvest or silvicultural treatment permitted. For the Bridger-Teton, these constraints were more restrictive on the programed harvest than on the potential yield.

Budget levels were established for each forest based on the expected level of funding, which represented a projection of past funding levels. By definition, the budget served as a constraint on just the programed harvest. Even then, the budget limited management activities on only the Lolo National Forest. Adequate budgets exist in part because some of the funds for intensive management come from timber sale receipts rather than appropriations.

Since the base alternative was designed to reflect the new timber managemnt plans on the sample forests, we attempted to duplicate assumptions, data, and procedures actually used in the new plans. However, on the Lolo National Forest, the acreage base changed after our study began, thus reducing the actual programed harvest below the figures we show. Furthermore, the forest is involved in a forest planning process that may affect the final harvest figures in other ways yet to be determined.

On the Bridger-Teton, a problem arose because a markedly different scheduling model was used. The model the forest used, ARVOL, essentially schedules harvest of existing stands in a simulation fashion. The model we used scheduled the harvest of existing and future stands so as to maximize harvest in the first decade. Thus, the two answers do not coincide. In spite of these differences, we feel the study results fulfill our purposes because we are interested in illustrating concepts that may apply to forests in general rather than in analyzing a specific policy on a particular forest.

No Reallocation Alternative

The no reallocation alternative consists of removing all the roadless areas from the timber harvest base without intensifying timber management or relaxing other constraints. This alternative is designed to measure the effects of placing all roadless areas on the forest in wilderness or in some other classification that would eliminate timber harvest as an alternative. The difference in timber harvest between this alternative and the base alternative represents a realistic estimate of the amount of harvest attributable to the roadless area. The harvest level is generally different than that presented in RARE II because less precise procedures were used in RARE II.

The acreages on the Bridger-Teton and Lolo National Forests used in this alternative were 343,000 and 1,070,000 acres (139 000 and 433 000 ha), respectively, for potential yield. The programed harvest on the Bridger-Teton was based on 149,000 acres (60 000 ha), whereas the Lolo remained at 1,070,000 acres (433 000 ha). The intensity of timber management was assumed to be the same as for the base alternative. Thus, fewer dollars were generally required because fewer acres were managed. Also, road costs were reduced substantially because the roadless areas were not roaded. Where necessary, multiple-use and environmental constraints were modified to reflect the reduced land base.

Reallocation Alternative

The purpose of the reallocation alternative was to show the effect on harvest and other outputs when roadless areas were excluded and the money saved by not developing roads was invested in intensive timber management on roaded areas instead. This alternative is identical to the previous alternative except that the budget for intensive timber management was increased by the amount of money that would have been spent roading the roadless areas on a decade-by-decade basis.

The amount of money available was determined by estimating the costs of road construction, reconstruction, and maintenance necessary to fully develop the roadless areas. The amount to be reallocated was equal to the costs avoided by not developing the roadless areas, less any increased costs incurred in the currently accessible areas as a result of not developing the roadless areas. No increased costs were projected for the two study forests.

The cost "saving" consisted of two components: (1) purchaser credits that would be generated from timber sale receipts in the roadless areas and (2) appropriated funds. If the roadless areas are not developed, purchaser credits are not available. This means that the reallocation alternatives could only be implemented if Congress appropriated additional money for intensive management.

Applying the cost savings to intensive management permitted increased thinning activity on the Lolo National Forest, but did not increase activities on the Bridger-Teton because the budget was not constraining there.

Partial Roadless Area Alternatives

To test the hypothesis that roadless areas do not contribute to the harvest in proportion to the amount of area involved, alternatives were identified in which only 50 percent of the roadless area was removed from the timber harvest base. Results we[re] projected for both programed harvest and potential yield with and without reallocati[on] of roading funds.

The selection of the half of the roadless area to be removed was based on: (1) the quality of the area for wilderness, (2) public concern for the area as wilderness, (3) congressional and administrative interest, (4) manageability, and (5) the direct and opportunity costs of permanent roadless designation. Because roadless areas were not subdivided, the 50 percent division was only approximated. Furthermore, this division was made on the basis of total forest lands in the roadless areas. The regulated commercial forest land in the first half of the roadless areas withdrawn represented 50 percent on the Bridger-Teton and 47 percent on the Lolo of the total commercial forest land in the roadless areas.

Because of some difficulties with the data, harvest computations representing the withdrawal of half of the roadless area were not made by computer for the Bridger-Teton National Forest. Instead, it was assumed that reducing the roadless area by half would halve the timber harvest attributable to the roadless area. Given the data available, this appears to have been a reasonable assumption.

HARVEST EFFECTS OF ROADLESS AREA WITHDRAWALS

When all of the roadless areas were removed from the timber harvest base and funds for intensive management were provided, the two forests studied here responded differently. The Lolo could make up 27 percent of the 66 MM bd.ft. loss through more intensive management. But the Bridger-Teton could not make up any of its 25 MM bd.ft. loss through more intensive management. These results, of course, depend upon the procedures and assumptions used in the study.

Procedures and Assumptions

The results were arrived at by simulating the current Forest Service timber management planning process. This involved the use of a linear programing model to schedule the harvest of stands over time. The data for the model were provided by the forest being studied and generally conformed to data actually being used in the timber management planning process.

The linear programing model, called Model II by Johnson and Scheurman (1977), determined the programed harvest and potential yield. In each case, timber harvest was maximized in the first decade subject to nondeclining yield on a decadal basis over time. Other constraints included number of acres allowed for regeneration harvest, species mix in harvest, access to certain areas, adequate ending inventory, and budget level.

The forest's data used in the model consisted primarily of existing and managed stand yield tables organized by species type, habitat type, type of silvicultural treatments, and general age or size of existing stands. Also included were the acres associated with each type, the multiple-use and environmental constraint levels, and various harvest controls. (Details may be obtained from K. N. Johnson, Department of Forestry and Outdoor Recreation, Utah State University, Logan.) In all cases, the timber data considered live green regulated material only. Wood from unregulated areas and dead timber was excluded.

Timber Harvest Levels

Programed harvest levels for the Bridger-Teton and Lolo National Forests are shown in figures 2 and 3, respectively. On the Bridger-Teton, the recent harvest was 75 percent of the base alternative harvest level, but on the Lolo the recent harvest was only about one-half of the base level. This is because of losses to wilderness, wilderness study, and RARE II, which were not considered in the study, and the lack of full funding of the timber sales program.

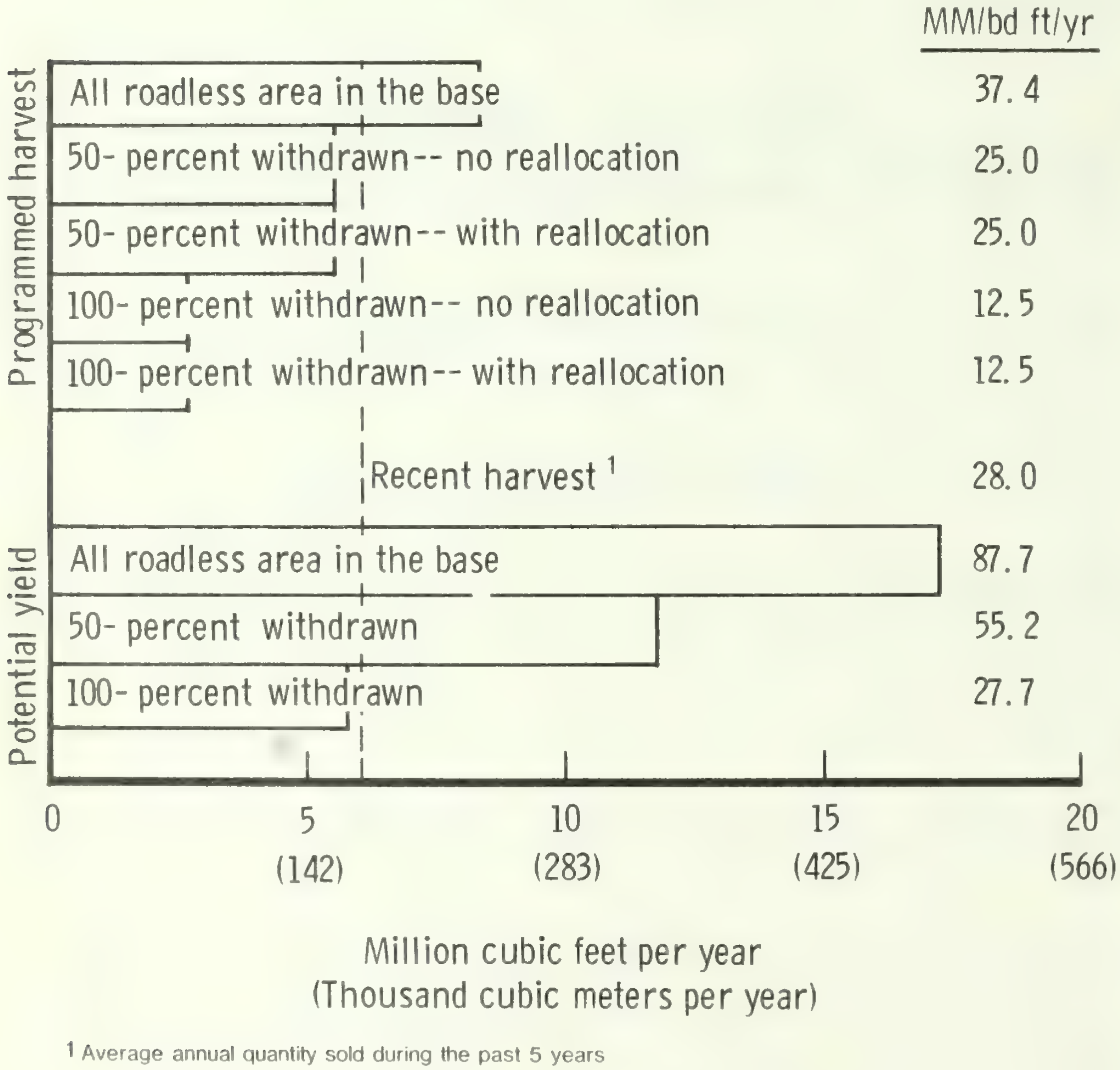
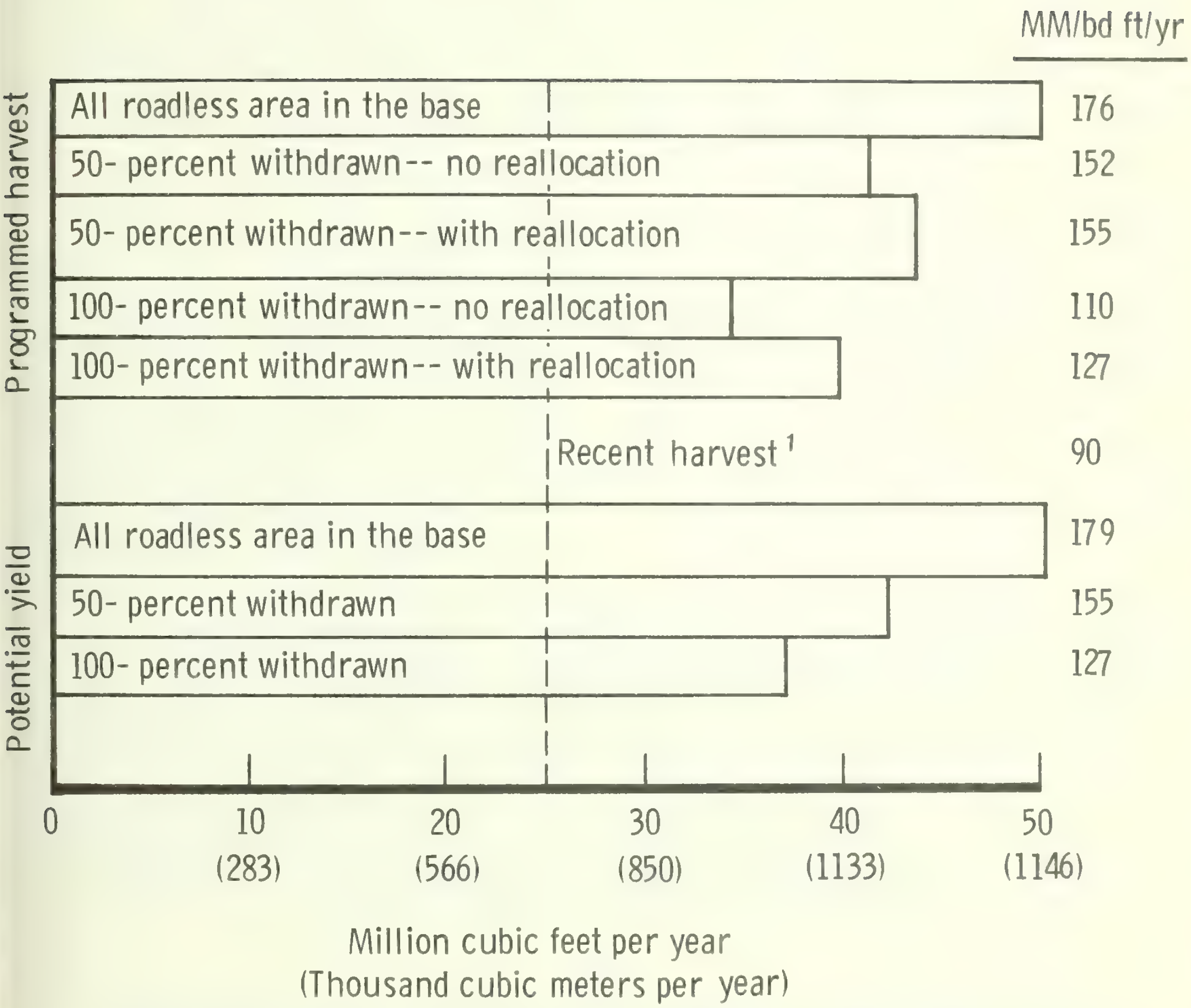


Figure 2.--Alternative harvest levels on the Bridger-Teton National Forest.



[1] The annual quantity sold the past 5 years is below the base program harvest primarily for the following reasons: (1) there have been losses of planned harvests through additions to wilderness, wilderness study, and RARE II, (2) there has not been sufficient funding for a complete timber sale program.

Figure 3.--Alternative harvest levels on the Lolo National Forest.

When all of the roadless areas were removed from the base, the programed harvest level dropped 67 and 38 percent, respectively, on the Bridger-Teton and Lolo. The Lolo could make up approximately one-quarter of this reduction, if roading funds were reallocated to intensive management. Even without the reallocation, the harvest level was above the recent sell. On the Bridger-Teton, there is no opportunity to offset any of the reduction in programed harvest through reallocation of funds to more intensive management of the remaining lands.

When one-half of the roadless area was removed the reduction of the programed harvest for the Bridger-Teton was directly proportional to the acres removed as explained earlier. However, on the Lolo removing one-half of the roadless areas reduced the programed harvest by only 14 percent or 24 MM bd.ft. Only 3 MM bd.ft. of this reduction could be made up by increased intensive management funding.

The potential yield on both forests is reduced in proportion to the acres removed. It is reduced 29 percent and 67 percent, respectively, on the Lolo and Bridger-Teton National Forests when all the roadless area is removed from the base. Those figures represent a reduction in commercial forest lands of 29 and 68 percent, respectively.

All the above results can be explained in terms of the constraints that are restrictive in the harvest scheduling model. On the Bridger-Teton with all roadless areas in the base, programed harvest is limited by the growth of the forest even though growth producing practices such as full stocking level control, prompt regeneration, removal of regeneration backlog, and thinning are assumed to be adequately funded. The difference between the base-programed harvest and the potential yield is produced by the harvest on marginal lands. Harvest there is limited by access, economics, technology, and possible environmental effects of harvesting.

When roadless areas on the Bridger-Teton are withdrawn from the base there are no opportunities to intensify timber management and the harvest is constrained by the number of acres of regeneration harvest allowed. Removing this constraint, which is designed to prevent environmental damage, would increase the programed harvest by more than 10 percent in the first decade.

The Lolo National Forest has similar limiting constraints. With half or all of the roadless areas in the timber harvest base, the harvest level is limited also by future yields of timber stands. When all the roadless areas are withdrawn, constraints on acres of regeneration and intermediate harvest become limiting. Constraints on intermediate harvests can be removed by additional funds to prepare low-volume sales of intermediate harvest on lands of low productivity.

In summary, losses of programed harvest on the Lolo National Forest caused by removal of roadless areas from the timber management base are more potential than real; however, losses will occur on the Bridger-Teton unless the uneconomic and environmentally sensitive marginal lands are brought into timber production. In both instances, the potential yield declines as acres are removed from the base.

FINANCIAL EMPLOYMENT EFFECTS

Financial Analysis Methods

The financial analysis quantifies the effect of the roadless area withdrawal alternatives on gross revenues, road costs, silvicultural costs, net revenues, in-lieu-tax payments to counties, and present net worth. The road cost data reflect the construction of roads to multiple-use standards. However, the financial analysis does not quantify all the land management benefits and costs associated with each alternative. For example, changes in the nontimber benefits of wilderness recreation and the

associated nontimber opportunity costs of foregone recreation opportunities are not included in the financial analysis because we do not now have defensible estimates of their monetary values. Direct management costs for resources other than timber are not included in the analysis either. Therefore, one cannot draw conclusions as to the economic efficiency of the harvest alternatives without evaluating the nontimber consequences presented in the final section of this report, along with the financial consequences presented here.

Financial results are shown for two roadless area withdrawal alternatives (50-percent and 100-percent withdrawn). They do not apply to individual roadless areas, and no conclusions can be reached as to the economic efficiency implications of a particular land allocation decision for a particular roadless area.

One of the most difficult problems in quantifying the financial consequences of roadless area withdrawals is how to account for the uncertainty regarding future prices and costs. To investigate the sensitivity of the financial results to alternative futures, two interest rates, two stumpage price trends, and two assumptions about future management costs are used in the financial analysis. Real interest rates, real stumpage prices, and real costs are used throughout the analysis. "Real" means that we make no attempt to project inflationary trends and do not incorporate inflation into the analytical methodology.

COST AND ASSUMPTIONS

The study forests provided cost data for reforestation, precommercial thinning, release, and timber sale preparation and administration (table 5). These data reflect the variable costs of the project, including labor, materials, and contract preparation and administration. The costs in table 5 do not include any charges for general administration or the overhead costs of program administration. On the Lolo National Forest, there are additional charges, equal to 1-1/2 times the timber sale cost, to cover deficit intermediate harvests when the intensity of timber management is increased.

Table 5.--*Silvicultural and timber sale preparation and administration costs for the Bridger-Teton and Lolo National Forests*[1]

Item	Bridger-Teton National Forest		Lolo National Forest	
	$/acre ($/hectare)	*$/M bd.ft.*	*$/acre ($/hectare)*	*$/M bd.ft.*
Reforestation[2]	160.00 (395.00)		250.00 (618.00)	
Release	65.00 (161.00)		57.00 (141.00)	
Precommercial thinning	65.00 (151.00)		57.00 (141.00)	
Timber sale preparation and administration		5.27		7.00

[1]Costs include contract preparation, contract costs, materials and labor, and contract administration. Costs exclude general administration and program management charges.
[2]Reforestation costs include site preparation and planting and apply to both harvested acres and nonstocked backlog.

Table 6 shows the road construction and road cost data provided by the forests. The road construction cost is the total cost that would be incurred to construct a road system in the roadless area. The road system is necessary to support the base programed harvest. Reconstruction and maintenance costs were also included in the financial calculations. For the harvest alternatives with one-half and all of the roadless area excluded from timber management, road construction, reconstruction, and maintenance costs were reduced to reflect the road system for the reduced land base plus any additional roading costs incurred in the currently accessible areas as a result of the reduced land base. All road costs reflect road construction to multiple use standards rather than the minimum standards for timber sale purposes.

Table 6.--*Road construction and road cost data*

Item	Bridger-Teton National Forest	Lolo National Forest
Total miles constructed to complete road system in roadless areas (kilometers)	1,185 (1 907)	2,931 (4 716)
Total construction costs ($1000's)	31,955	75,000
Cost-dollars per mile ($/kilometer)	26,966 (16 757)	25,588 (15 903)
Construction percent by decade[1]		
First decade	20	20
Second decade	20	20
Third decade	20	18
Fourth decade	20	15
Road miles per section (kilometers/1 000 hectares), in roadless areas		
Regulated commercial forest land acres (Bridger-Teton based on 734,000 acres [297 000 hectares])	1.0 (6.4)	4.4 (27.1)
Total National Forest acres (Bridger-Teton based on 1,750,000 acres [708 000 hectares])	.4 (2.7)	2.5 (15.4)
Reconstruction cost-dollars per mile ($/kilometers)	9,400 (5 800)	1,800 (1 100)
Reconstruction cycle in years	--	30
Maintenance costs-dollars per mile per year ($/kilometer/year)	365 (227)	141 (88)

[1]The percentages do not sum to 100 because the road system is not expected to be completed within four decades.

The success of dealing with uncertainty through sensitivity analysis depends on the thoughtful selection of alternative views of the future. Two assumptions about the future course of real costs (costs without inflation) were used in the financial analysis. The first assumption was that future real costs for all conditions would remain at the same levels as shown in tables 5 and 6.

The second cost assumption was that the cost per acre for those practices which use a relatively large quantity of labor would increase at the same rate as projected real per capita income in the Rocky Mountain States, Idaho, Utah, Nevada, Wyoming, Montana, Colorado, and South Dakota. (This assumption is based on empirical evidence gathered by Connaughton.) All other cost items were assumed to remain constant in real terms. Specifically, costs for reforestation, precommercial thinning, and timber sale preparation and administration were assumed to increase at the same rate as the U.S. Water Resources (1974) projections of real per capita income in the Rockies to the year 2020. The increase in real costs of these items is approximately 2.6 percent per year (compounded) over the period 1980 to 2020. Costs were assumed constant after that. The compound annual growth rate of real per capita income in the Rocky Mountain States for selected years between 1970 and 2220 is shown in appendix A.

STUMPAGE PRICE DATA AND ASSUMPTIONS

The prices received for stumpage may be different in the roadless areas from those on the currently accessible areas because of differences in species mix, timber quality, and logging and hauling costs. These factors were accounted for when we developed separate prices on each forest for each half of the roadless area and for the accessible area. The high bid prices for each area were provided by the forests and are shown in table 7. The high bid represents the price of stumpage as if the road system were in place. The prices shown in table 7 represent 1977 stumpage prices that were trended to average out recent fluctuations in stumpage markets.

Two assumptions were made about the future course of stumpage prices. The first was that future stumpage prices would be constant at the same level as the 1977 high bid prices reported by the forests (table 7). The second price assumption was that real stumpage prices would be increasing over time from their 1977 levels.

Table 7.--*High bid stumpage prices for the Bridger-Teton and Lolo National Forest, 1977*

Area	Bridger-Teton National Forest: Lodgepole pine type	Bridger-Teton National Forest: Englemann spruce-subalpine fir type	Bridger-Teton National Forest: Douglas-fir type	Lolo National Forest
	$/M bd.ft.			
Accessible	58.76	69.69	64.99	73.00
Roadless area 2[1]	57.51	68.44	63.74	73.00
Roadless area 3[2]	55.50	66.44	61.74	73.00

[1]Roadless area 2 includes the half of the roadless areas most likely to remain in the timber base.
[2]Roadless area 3 includes the half of the roadless areas most likely to remain roadless.

The increases in real stumpage price for the second price assumption came from an early version of the Resources Planning Act Timber Assessment Softwood Market Model.[1] Prices on both study forests were projected to increase at an average annual compound rate of 1.5 percent from 1978 to 2030. We assumed that prices would remain constant after 2030. The stumpage price projections used in the financial calculations for each forest are reported in appendix B, tables 16, 17, 18, and 19.

In the absence of data on harvest changes caused by roadless withdrawals on other forests, we consider the increasing price assumption to be the more realistic. Results calculated with increasing prices are highlighted in the financial results section. We know, however, that roadless withdrawals on other national forests have the potentia of affecting total Forest Service harvest levels in the Rocky Mountain States. Reductions in total Forest Service harvest caused by roadless area withdrawals would likely lead to future stumpage prices that would be relatively higher than those in this analysis, despite the price responsive behavior of private stumpage owners and the price responsive flows of products in the manufactured wood products markets. Higher future prices would lead to larger changes in gross revenue, net revenue, county payments, and present net worth than those reported in the financial results section.

Results calculated with constant prices are briefly referred to in the financial results section and are reported in detail in appendix C, tables 20 and 21.

DISCOUNT RATES AND DISCOUNTING

Two discount rates, 5 and 10 percent, were used in present net worth calculations Five and 10 percent represent a range in rates that is wide enough to reveal the sensitivity of the financial results to the cost of capital. The 5 to 10 percent range also avoids the difficulties of attempting to identify a single "correct" discou rate for public investment evaluation. The range includes the 5 to 6 percent after-ta real rate that Klemperer (1976) concludes is competitive for private forestry.

Present net worths shown in the financial results section and in appendix C, tables 20 and 21, were calculated for 10 decades with the following relationship:

$$PNW = \sum_{n=1}^{10} \frac{r_n[(1+i)^{10} - 1]}{i(1+i)^{10n}}$$

where

PNW = present net worth,
r_n = average annual net revenue received in the nth decade,
i = discount rate ($i = 0.05, 0.10$),
n = decade ($n = 1, ..., 10$).

[1]Adams, Darius M., and Richard W. Hayes. 1978. A preliminary description of the 1980 timber assessment softwood market model. Internal report on file at the Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Employment Analysis Methods

Estimates of the changes in employment resulting from various harvest levels were derived from local input-output tables. These were developed as part of the RARE II analysis for most study forests including the Lolo. The data shown in table 8 for Missoula, Mineral and Sanders Counties were used to scale down the national input-output table to the local level for the Lolo National Forest. Analysis using this local table indicated a change in total employment of 20 man-years for each million board feet processed by the forest products industry in these counties.

The data for measuring the employment impacts resulting from changes in Bridger-Teton harvest differed from data used elsewhere. The two input-output regions developed for western Wyoming in RARE II did not adequately represent the forest's log flows. the two input-output regions developed for western Wyoming in RARE II did not adequately represent the forest's log flows since only one included county was a log destination while three excluded counties were log destinations. Consequently, an export base model was developed using covered employment in Fremont and Lincoln Counties in Wyoming and Fremont and Madison Counties in Idaho (table 9). The multiplier derived from this analysis was combined with the employment consumption ratio of a nearby county to produce a total employment effect of 16 employees per million board feet processed.

The results for both forests represent the sum of direct, indirect, and induced employment effects resulting from the harvest changes on each forest. The direct employment effect is the change in employment in the wood products manufacturing and timber supply sectors associated with changes in final demand sales of each sector. The indirect component consists of the changes in employment in all other sectors (with the exception of households) resulting from the changes in final demand sales of the wood products manufacturing and timber supply sectors. The induced employment effect is that change resulting from the spending actions of local households.

The employment consequences of the harvest alternatives apply only to the local economies--economies for which the study forests are an important source of forest-related goods and services. The reported impacts are not the only employment consequence of the harvest alternatives, and the choice of a greater employment impact region would lead to a different set of employment results. However, it is at the local level where the effects of harvest changes and land allocation decisions are felt most heavily and where employment concerns are likely to be greatest.

The employment results should also be considered in light of the scope within which they were developed. First, changes in harvest levels were directly translated into changes in sales to final demand from the local wood products processing and timber supply sectors. No compensating adjustments in harvest flows from non-Forest Service ownerships or nonlocal sources were recognized. Second, the employment results in short-term effects only. The difficulty of accurately assessing the future course of labor productivity and structural change within the local economy precludes a projection of the employment consequences over several decades. Third, we believe increases in dispersed, nonmotorized recreation-related employment that would result from all of the roadless areas remaining in a roadless status are likely to be offset by employment losses from decreases in dispersed, motorized recreation-related employment. No attempt is made to estimate the total employment effect of changes in payments to counties. Finally to the extent that the base programed harvest is greater than the recent volume of chargeable harvest, employment reductions stemming from harvest reductions represent decreases in opportunities to expand employment rather than decreases in the actual level of employment.

Table 8.--*Original data for 14-sector input-output model for the Lolo National Forest*[1]

Sector	Final demand ($1000's)	Total gross output ($1000's)	Labor	Income ($1000's)	Value added ($1000's)
			Man-years		
Livestock agriculture	4,068	10,336	1,023	2,452	2,590
Other agriculture	4,664	8,012	497	2,466	3,656
Mining	1,205	1,807	56	89	705
Construction	48,636	54,880	1,948	17,693	24,217
Forest products industry	124,384	164,404	4,270	33,589	
All other manufacturing	48,749	69,525	946	9,295	26,419
Transportation, communication and utilities	48,666	72,611	2,614	26,546	47,051
Wholesale trade	16,236	27,585	1,611	15,081	18,338
Auto dealers - gas stations	12,730	13,686	1,158	7,764	10,460
Eating and drinking places	24,146	24,913	2,108	10,468	19,003
Other detail trade	35,855	39,446	2,540	19,762	30,088
Finance, insurance, real estate	23,130	32,813	1,181	10,228	22,565
Lodging	10,631	10,734	648	2,816	5,375
Other services	40,007	65,556	6,280	29,789	38,588
Private sectors total	443,107	596,308	26,880	188,039	309,518
Government and miscellaneous			6,436	62,248	93,372
Total	443,107	596,308	33,316	250,287	402,890

[1] Includes Missoula, Mineral, and Sanders Counties.

Table 9.--*Covered employment*[1] *for Counties influenced by Bridger-Teton timber harvest, 1976 (U.S. Bureau of Census 1977)*

County	Total number employees	Number basic[2] employees	Wood products industry employees
Wyoming			
Lincoln	2,159	1,017	125[3]
Fremont	7,629	2,516	117
Idaho			
Fremont	1,366	395	100[3]
Madison	3,352	459	70[3]
Totals	14,506	4,387	412

[1] Includes those covered under Federal Insurance Contributions Act except government, self-employed, farm, domestic, and railroad employees.
[2] Includes employees in agriculture, mining, and manufacturing.
[3] Estimates used to avoid disclosure.

Financial and Employment Consequences on Study Forests

Two sets of financial results were calculated using different price and cost assumptions. Results assuming increasing real costs and prices are shown in the text. Those assuming constant real costs and prices are shown in appendix C, tables 20 and 21.

BRIDGER-TETON NATIONAL FOREST

Gross revenue, silvicultural costs, road costs, timber sale costs, net revenue, county payments, present net worth and employment all decline when the roadless areas are withdrawn from the timber management base (table 10). Although the absolute harvest level on the Bridger-Teton is not as great as on the Lolo, the roadless areas on the Bridger-Teton contribute a substantial portion of the volume to the timber program. Since the changes in financial and employment impacts are highly correlated with these harvest changes, the financial and employment consequences depend heavily on whether or not the roadless areas are available for timber harvesting. Present net worth will probably increase when roadless areas are withdrawn, if the marginal lands added to produce the potential yield were programed for harvest in the base alternative. This is because these lands are generally uneconomic to harvest with the present technology, costs, and markets for timber.

When constant real costs and constant real prices (appendix C) are used in the financial analysis the results are similar to those reported for the increasing cost/price assumption. However, the reductions in present net worth are much less than those reductions observed with increasing prices and costs. These results are obtained because present net worth calculations give less weight to future decades--decades in which stumpage prices are considerably higher than they are now. With constant prices and costs, the reductions in present net worth are less when all of the roadless areas are withdrawn than when only one-half of the roadless areas are withdrawn. This result occurs because the lower prices do not generate enough revenue to offset the savings in road costs, which are higher for the second half of the roadless area than for the first half.

Wood products dependent employment is reduced by 200 and 400 person years for the one-half roadless and the all roadless areas out alternatives, respectively. This is probably a high estimate of the total employment effect.

LOLO NATIONAL FOREST

Table 11 shows that gross revenue, net revenue, present net worth, and costs move in the same direction as harvest changes on the Lolo National Forest. A comparison of the results for the 50 percent withdrawn and the 100 percent withdrawn alternatives shows that the reductions in the financial values are approximately proportional to reductions in harvest. Payments to counties may not be affected by harvest levels on this forest, because alternative payments may be elected by the counties.

Wood products-dependent employment is reduced by 420 person years when half of the roadless areas are withdrawn and by 980 when all of the roadless areas are withdrawn from timber harvesting. Since the present harvest is less than the reduced level, these reductions in employment represent lost potential rather than actual employment.

Table 10.--*Forty-year-average financial effects and employment effects of withdrawing roadless areas and reallocating funds to intensive management*[1]*, Bridger-Teton National Forest*

Item	Base programed harvest	Change from base when 50 percent roadless withdrawn	Change from base when 100 percent roadless withdrawn
Harvest (MM bd.ft./yr)	37.4	-12.4	-24.9
Gross revenue ($1 million/yr)	3.7	-1.2	-2.4
Cost of roads ($1 million/yr)	NA	- .4	- .9
Cost of cultural treatments ($1 million/yr)	NA	- .3	- .6
Cost of selling timber ($1 million/yr)	NA	- .1	- .2
Net revenue (Item 2-items 3, 4, and 5) ($1 million/yr)	NA	- .4	- .7
Payments to counties[2] ($1 million/yr)	0.9	- .3	- .6
Present net worth for 10 decades at 5 percent ($1 million)	NA	-8.1	-15.8
Present net worth for 10 decades at 10 percent ($1 million)	NA	-4.0	-7.8
First decade average[3] annual total employment (man-years)	600	-200	-400

NA = not available

[1]Trends in real costs and real stumpage prices expected with no harvest changes due to roadless area withdrawals on other national forests in Regions 1, 2, 3, and 4 were used.

[2]Based on 25 percent of gross receipts. Actual value may be greater and not vary between alternative withdrawals.

[3]Because recent harvest is 25 percent less than the base programed harvest, 150 man-years are potential employment and the rest is actual.

Table 11.--*Forty-year-average financial and employment effects of withdrawing roadless areas and reallocating funds to intensive management*[1], *Lolo National Forest*

Item	Base programed harvest	Change from base when 50 percent roadless withdrawn	Change from base when 100 percent roadless withdrawn
Harvest (MM bd.ft./yr)	176.0	-21.0	-49.0
Gross revenue ($1 million/yr)	21.5	-2.5	-5.9
Cost of roads ($1 million/yr)	NA	- .7	-1.5
Cost of cultural treatments ($1 million/yr)	NA	- .9	-2.0
Cost of selling timber ($1 million/yr)	NA	- .3	- .6
Net revenue (Item 2-items 3, 4, and 5) ($1 million/yr)	NA	- .6	-1.8
Payments to counties ($1 million/yr)[2]	5.4	- .6	-1.5
Present net worth for 10 decades at 5 percent ($1 million)	NA	-17.1	-35.3
Present net worth for 10 decades at 10 percent ($1 million)	NA	-7.1	-14.8
First decade average[3] annual total employment (man-years)	3,510	-420	-980

NA = not available

[1]Trends in real costs and real stumpage prices expected with no harvest changes caused by roadless area withdrawals on other national forests in Regions 1, 2, 3, and 4, were used.

[2]Based on 25 percent of gross receipts. Actual value may be greater and vary less between alternative withdrawals.

[3]Because the recent harvest on the Lolo National Forest is near the programed harvest with all of the roadless area withdrawn, reduction in revenues and employment represent losses in opportunities for increases rather than reductions from actual recent levels.

Conclusions About the Financial and Employment Consequences of Roadless Withdrawals

Gross revenue, net revenue, costs, present net worth, and employment decline on both forests when all or half of the roadless areas are withdrawn from the timber management base. The roadless areas on the Lolo make a financial contribution to the timber program that is larger in absolute value than the contribution made by the roadless areas on the Bridger-Teton. However, in relative terms, the roadless areas on the Bridger-Teton make a larger contribution to the financial value of the timber program than do such areas on the Lolo.

The employment changes on both forests are directly proportional to the harvest changes. With all roadless areas withdrawn, the employment losses are 980 and 400 person years on the Lolo and Bridger-Teton, respectively.

CHANGES IN ENVIRONMENTAL CONDITIONS AND NONTIMBER BENEFITS

Background

This section of the report demonstrates that the roadless area issue involves many kinds of trade-offs concerning environmental conditions and nontimber benefits. The trade-offs examined are those attributable to withdrawing roadless areas from the timber base and reallocating road funds to intensify timber management on remaining areas. We focus our analysis of nontimber impacts on a comparison of the alternative, 100 Percent Roadless Area Out--Reallocation (of roading funds), with the base alternative.

Impacts were estimated for five decades into the future for each nontimber benefit criterion. Major, minor, and neutral impacts were recognized according to their timing (decades one, two through four, and five), nature (adverse or beneficial), and, in the case of major adverse impacts, the costs of mitigation.

Major impacts were identified as those that exceeded the "threshold of concern," which is defined as the amount of impact that would generate one or more of these effects: (1) create a public expression of concern or interest, (2) change long-term traditional use patterns, and (3) require funds substantially in excess of usual planning and budgeting levels to mitigate impacts to an acceptable level. Major adverse impacts, while undesirable, are within limits considered acceptable under current interpretation of multiple-use objectives.

We obtained those impacts by meeting with resource specialists from the various disciplines on each study forest. We provided road schedules, schedules of intermediate and regeneration harvest, and acres of management activities. The specialists reviewed the differences in these data between the base alternative and the reallocation alternative. Then, they interpreted these differences in terms of their effects on nontimber benefits and ecosystem criteria. For this report, forest data were divided into a roadless portion and an accessible portion. Each was evaluated seperately.

Present Situation

Before dealing with the impacts of withdrawing roadless areas and reallocating funds to more intensive management, we will briefly discuss the impact of the base alternative compared with the current situation.

Since 1972, all RARE I roadless areas and some more recently identified RARE II areas have been closed to timber harvesting, except where they have been allocated to such use through a completed land management plan. Consequently, on many National Forests, most roadless areas are still unavailable for timber harvest even though they are included in the commercial forest land base, on which allowable harvests are calculated. As a result, road construction and timber harvesting have been concentrated outside the roadless areas since 1972. Adverse environmental impacts are beginning to develop and are in danger of exceeding acceptable levels on many national forests. As the interdisciplinary teams have pointed out, there will be both beneficial and adverse impacts in going from the present condition to the base programed harvest. It is not our purpose, however, to evaluate these effects. We focus entirely on the changes expected to take place between the base programed harvest and reallocation alternative because these are the impacts that are relevant to the choice between the two.

Comparison of Alternatives and Criteria

The impacts presented here represent changes from the base alternative. Generally trade-offs exist between the various criteria and between the roadless and accessible areas within each criterion. Impacts related to roadless areas are generally those on the base alternative that are avoided by the adoption of the reallocation alternative.

Our experience in this study has confirmed findings that were evident in the Timber Harvest Scheduling Issues Study (USDA 1976). Specifically, impacts on nontimber resources are site specific; they may be variable within a forest; and they often exhibit great variability between forest and regions. For these reasons, we did not try to extrapolate regional impacts from the study forest.

In the following discussion, the criteria impacts are identified and briefly discussed and the results of the analysis of the impacts are presented for each forest.

WATER QUALITY

Slope failure associated with timber harvests and roadbuilding activities, including the selection of road sites, design, construction methods, and maintenance levels, are critical factors affecting the present water quality levels in managed forest watersheds. Sediment introduced to forest streams determines, to a large extent, the impact on water quality.

WATER QUANTITY AND TIMING OF FLOW

Impacts on water quantity and timing of flow are considered together here. In areas with abundant water, such as the Douglas-Fir region of the Pacific Northwest, impacts on total water quantity are less important than impacts related to peak flows. On forests adjacent to semiarid areas, quantity may be more important. In both the water-abundant and the semiarid areas, specialists expressed concern with peak flows reaching critical levels.

SOIL STABILITY

Erosion and mass soil movement are the major soil stability problems. Both can affect water quality; in addition, mass movements can also be a threat to life and property. The risk of soil stability problems is increased by road construction and timber harvesting operations. The risk is also influenced by steepness of terrain and soil characteristics.

SOIL PRODUCTIVITY

Soil productivity problems resulting from timber harvesting and roadbuilding activities take the form of compaction and nutrient loss. How residues are handled is usually considered the critical factor affecting nutrient levels. The frequency of timber harvests on a given site and the type of machinery used are critical factors affecting soil compaction.

FORAGE PRODUCTION

On western national forests, forage production often occurs on forested ranges that are utilized during the summer grazing season. A close relationship exists between the amount of forage used and the location and terrain of harvested acres. The terrain must be negotiable by domestic livestock and located in the proximity of existing active grazing allotments.

RESIDENTIAL COLD WATER FISH POPULATIONS

Fish populations are directly related to habitat conditions, of which water quality is a critical factor. Hence, impacts on fish populations generally relate closely to impacts on water quality.

WILDLIFE POPULATIONS

The level of given wildlife populations is strongly influenced by the presence or absence of certain habitat types and their successional stages. Road construction and timber harvest activities impact habitat types by altering the numbers, size, age, arrangement, and species composition of timber stands that comprise a forest.

OPPORTUNITIES FOR DEVELOPED RECREATION

Opportunities for developed recreation usually involve a relatively high density form of recreation centered around a developed site, such as a campground, a boat launch, or a marina. Frequently, the developed facility is located at or near a natural land feature, such as a lake, stream, waterfall, or scenic vista that provides an attractive setting. Manmade improvements may vary from primitive to relatively elaborate.

OPPORTUNITIES FOR DISPERSED RECREATION RELATED TO ROADS

Opportunities for dispersed recreation related to roads are scattered, individual activities usually not associated with developed areas.

OPPORTUNITIES FOR DISPERSED RECREATION AWAY FROM ROADS

Opportunities for dispersed recreation away from roads are backpacking, horseback riding, and various types of off-road vehicle experiences. Many of these activities involve a more primitive form of camping than is normally associated with developed or road-related dispersed recreation.

VISUAL RESOURCES

In this paper, the term "visual resources" refers to opportunities for viewing natural-appearing forest landscapes from a distance. Generally, a direct relationship exists between visual resources and the acres disturbed at any time. Following timber harvest, impacts tend to be adverse in the short run. They can be minimized through proper shaping of the harvest units to the natural characteristics of the land.

AIR QUALITY

Smoke from burning slash is the principal source of air pollutants associated with timber management activities. The impact on air quality is, however, a seasonal problem that smoke management plans have largely overcome on many forests. In the long run, increased utilization and conversion of overmature forests to younger, less defective stands will reduce the need for burning slash.

MINERAL AND ENERGY DEVELOPMENT OPPORTUNITIES

At present, opportunities to efficiently develop mineral and energy resources are directly enhanced by the presence of a road system. On most forests, no other form of access is currently feasible for utilizing mineral and energy resources.

Bridger-Teton National Forest Results

If the reallocation alternative were adopted in place of the base alternative on the Bridger-Teton National Forest, no roads would be built and no road-related timber harvest would occur in the roadless areas of the forest. Specialists would anticipate two major adverse and five major beneficial nontimber or environmental impacts. All of the major impacts would be associated with roadless areas. Also expected by the specialists are 7 minor adverse, 4 minor beneficial, and 12 neutral nontimber or environmental impacts. All of these impacts are listed in table 12.

Table 12.--*Summary of estimated impacts associated with withdrawing the roadless areas and intensifying timber management on the remaining land in the Bridger-Teton National Forest*[1]

Criteria	Impacts: Beneficial Major	Beneficial Minor	Neutral No change from base	Adverse Minor	Adverse Major[2]
Water quality	R			A	
Water quantity			A	R	
Waterflow			A,R		
Soil stability		R		A	
Soil productivity			A,R		
Forage production (domestic)			A	R	
Fish populations (residential)	R		A		
Wildlife populations (game species)	R			A	
Wildlife populations (threatened and endangered species)	R		A		
Recreation opportunities (developed)			A	R	
Opportunities for dispersed recreation related to roads		A			R
Opportunities for dispersed recreation away from roads	R			A	
Visual resources		R	A		
Air quality			A,R		
Mineral and energy development		A			R

[1]R = Roadless areas, A = Accessible areas.

[2]Major adverse impacts, although undesirable, are within limits considered acceptable under current interpretation of multiple-use objectives.

The major beneficial impacts of the reallocation alternative involve water quality, fish and wildlife populations, and dispersed recreation away from roads. The beneficial impacts on fish populations relate to the opportunity to avoid habitat degradation in the roadless areas. For wildlife populations of game, primarily elk, moose, and bighorn sheep and threatened and endangered species, primarily grizzly bear, gray wolf, and bald eagle, the major anticipated beneficial impacts result from the opportunity to avoid intensive road-related timber management in the roadless areas. Finally, for dispersed recreation opportunities away from roads, the beneficial impacts result from the opportunity to avoid reducing the roadless areas.

The major adverse impacts involve dispersed recreation opportunities related to road, mineral, and energy development. The adverse impact on road-related dispersed recreation results from opportunities foregone to increase the accessible area. The adverse impact on mineral and energy development relates to the opportunity foregone to gain access to the roadless areas.

In summary, when the reallocation alternative is adopted in place of the base alternative, specialists on the Bridger-Teton National Forest would anticipate major nontimber trade-offs in addition to the loss of timber harvests listed in figure 2. Water quality, fish, wildlife, and dispersed recreation away from roads would be expected to benefit at the expense of dispersed recreation related to roads and of mineral and energy development.

Lolo National Forest Results

If the reallocation alternative were adopted in place of the base alternative on the Lolo National Forest, no roads would be built and no road-related timber harvests would take place in the roadless areas of the forest. Specialists would anticipate one major adverse and five major beneficial nontimber or environmental impacts. Four of these six major impacts would be associated with the roadless areas and two with the accessible areas. Also expected by the specialists are three minor adverse impacts, six minor beneficial impacts and 15 neutral nontimber or environmental impacts. All impacts are listed in table 13.

The major beneficial impacts of the reallocation alternative involved water quality, soil stability, forage, and wildlife populations of game species. The beneficial impacts on water quality and soil stability result from the opportunity to avoid sedimentation, erosion, and mass soil movement in the roadless areas. With forage, the beneficial impacts are associated with the opportunity to increase forage production in the accessible areas. For wildlife populations of game species, the beneficial impacts result from opportunities to avoid a reduction of desirable habitat, mainly cover in the roadless areas, and to increase browse and cover in the accessible areas.

The major adverse impact, forage production in roadless areas, results from the opportunity foregone to increase forage production in the roadless areas when they are withdrawn from the commercial forest land base.

In summary, adoption of the reallocation alternative in place of the base alternative would cause specialists on the Lolo National Forest to anticipate major nontimber and environmental trade-offs in addition to the loss of timber harvest. Water quality, soil stability, and wildlife populations would benefit in the roadless areas and forage production and wildlife populations would benefit in the accessible areas at the expense of forage production in the same areas.

Table 13.--*Summary of estimated impacts associated with withdrawing the roadless areas and intensifying timber management on the remaining land in the Lolo National Forest*[1]

Criteria	Impacts: Beneficial		Impacts: Neutral	Impacts: Adverse	
	Major	Minor	No change from base	Minor	Major[2]
Water quality	R			A	
Water quantity			A,R		
Waterflow		R	A		
Soil stability	R		A		
Soil productivity			A,R		
Forage production (domestic)	A				R
Fish populations (residential)		R	A		
Wildlife populations (game species)	A,R				
Wildlife populations (threatened and endangered species)		R	A		
Recreation opportunities (developed)			A,R		
Opportunities for dispersed recreation related to roads			A	R	
Opportunities for dispersed recreation away from roads		R	A		
Visual resources		R	A		
Air quality		R	A		
Mineral and energy development			A	R	

[1]R = Roadless areas, A = Accesible areas.

[2]Major adverse impacts, although undesirable, are within limits considered acceptable under current interpretation of multiple-use objectives.

CONCLUSIONS

A summary of some consequences of intensifying timber management as roadless areas are withdrawn from timber production is presented in table 14. In general, there is little opportunity to offset potential timber harvest reductions through intensive management as roadless areas are removed. Consequently, present net worth, payments to counties, and employment may be reduced along with forage production, dispersed recreation related to roads, and mineral and energy development. On the other hand, fish and game populations, water quality, soil stability, and opportunities for dispersed recreation experiences away from roads may be improved. Although it is tempting to extrapolate these consequences to other forests in the regions studied, great care must be exercised because the variability between forests is so great.

Table 14.--*Consequences of changing from the base alternative to 100 percent removal of roadless areas with reallocations of roading funds to intensive management by forest*

Criteria	Bridger-Teton National Forest	Lolo National Forest
Programed harvest (MM bd.ft.)	-25	-49
Potential Yield (MM bd.ft.)	-55	-52
Roads (miles, kilometers)	-1185, 1907	-2931, 4716
Present net worth at 5 percent ($1 million)	-15.8	-35.3
Employment (man-years)	-400	-980
Water quality	Major beneficial (R)[1]	Major beneficial (R)
Forage production	Minor adverse (R)	Major beneficial (A)[2] and adverse (R)
Fish population	Major beneficial (R)	Minor beneficial (R)
Big game population	Major beneficial (R)	Major beneficial (A,R)
Threatened and endangered species	Major beneficial (R)	Minor beneficial (R)
Dispersed recreation related to roads	Major adverse (R)	Minor adverse (R)
Dispersed recreation away from roads	Major beneficial (R)	Minor beneficial (R)
Mineral and energy development	Major adverse (R)	Minor adverse (R)

[1]R = roadless areas.
[2]A = accessible areas.

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APPENDIXES

APPENDIX A

Annual Compound Growth Rate of Real Per Capita Income in the Rockies, 1978-2020

Table 15.--*The annual compound growth rate (percent) of real per capita income in the Rockies[1], 1978-2020*

Year	1983	1993	2003	2013	2020
1978	3.19	2.78	2.71	2.68	2.59
1983	--	2.58	2.59	2.60	2.51
1993	--	--	2.60	2.61	2.49
2003	--	--	--	2.62	2.42
2013	--	--	--	--	2.14

Source: U.S. Water Resources Council, 1974.

[1]The Rockies include Idaho, Utah, Nevada, Montana, Wyoming, Colorado, and South Dakota.

APPENDIX B

Real Stumpage Price Assumptions Used for Study Forests

Table 16.--*Real stumpage price in 1978 dollars Lolo National Forest*

Decade	Constant in all areas[1]	Increasing in all areas[2]
	- - - - *Dollars per thousand board feet* - - - -	
First	73.15	94.59
Second	73.15	124.89
Third	73.15	131.83
Fourth	73.15	138.98
Fifth	73.15	146.22
Sixth	73.15	154.49
Seventh	73.15	154.49
Eighth	73.15	154.49
Ninth	73.15	154.49
Tenth	73.15	154.49

[1]High bid price reported by the forest.

[2]Resources Planning Act Timber Assessment Softwood Market Model projections from 1978 high bid price levels.

Table 17.--*Real stumpage price in 1978 dollars Bridger-Teton National Forest--lodgepole pine timber type*

Decade	Constant prices[1 3]			Increasing prices[2 3]		
	All roadless areas in	50 percent roadless areas out	All roadless areas out	All roadless areas in	50 percent roadless areas out	All roadless areas out
	Dollars per thousand board feet					
First	47.59	48.28	48.76	74.16	75.24	75.99
Second	47.59	48.28	48.76	95.59	96.99	97.94
Third	47.59	48.28	48.76	98.71	100.16	101.15
Fourth	47.59	48.28	48.76	102.98	104.49	105.52
Fifth	47.59	48.28	48.76	108.35	109.94	111.03
Sixth	47.59	48.28	48.76	115.11	116.79	117.95
Seventh	47.59	48.28	48.76	115.11	116.79	117.95
Eighth	47.59	48.28	48.76	115.11	116.79	117.95
Ninth	47.59	48.48	48.76	115.11	116.79	117.95
Tenth	47.59	48.28	48.76	115.11	116.79	117.95

[1]High bid price reported by the forest.
[2]Resources Planning Act Timber Assessment Softwood Market Model projections from 1978 high bid price levels.
[3]Prices vary by land base because of differences in logging and hauling costs and in timber quality.

Table 18.--*Real stumpage price in 1978 dollars Bridger-Teton National Forest--Englemann spruce-subalpine fir type*

Decade	Constant prices[1] [3]			Increasing prices[2] [3]		
	All roadless areas in	50 percent roadless areas out	All roadless areas out	All roadless areas in	50 percent roadless areas out	All roadless areas out
	Dollars per thousand board feet					
First	56.88	57.47	57.83	88.64	89.57	90.12
Second	56.88	57.47	57.83	114.26	115.45	116.16
Third	56.88	57.47	57.83	118.00	119.23	119.96
Fourth	56.88	57.47	57.83	123.10	124.39	125.15
Fifth	56.88	57.47	57.83	129.52	130.87	131.68
Sixth	56.88	57.47	57.83	137.59	139.03	139.89
Seventh	56.88	57.47	57.83	137.59	139.03	139.89
Eighth	56.88	57.47	57.83	137.59	139.03	139.89
Ninth	56.88	57.47	57.83	137.59	139.03	139.89
Tenth	56.88	57.47	57.83	137.59	139.03	139.89

[1]High bid price reported by the forest.
[2]Resources Planning Act Timber Assessment Softwood Market Model projections from 1978 high bid price levels.
[3]Prices vary by land base because of differences in logging and hauling costs and in timber quality.

Table 19.--*Real stumpage price in 1978 dollars Bridger-Teton National Forest--Douglas-fir type*

Decade	Constant prices[1,3]			Increasing prices[2,3]		
	All roadless areas in	50 percent roadless areas out	All roadless areas out	All roadless areas in	50 percent roadless areas out	All roadless areas out
	Dollars per thousand board feet					
First	52.99	53.57	53.93	82.85	83.49	84.04
Second	52.99	53.57	53.93	106.45	107.62	108.33
Third	52.99	53.57	53.93	109.93	111.14	111.87
Fourth	52.99	53.57	53.93	114.68	115.95	116.71
Fifth	52.99	53.57	53.93	120.66	121.99	122.80
Sixth	52.99	53.57	53.93	128.18	129.60	130.45
Seventh	52.99	53.57	53.93	128.18	129.60	130.45
Eighth	52.99	53.57	53.93	128.18	129.60	130.45
Ninth	52.99	53.57	53.93	128.18	129.60	130.45
Tenth	52.99	53.57	53.93	128.18	129.60	130.45

[1]High bid price reported by the forest.
[2]Resources Planning Act Timber Assessment Softwood Market Model projections from 1978 high bid price levels.
[3]Prices vary by land base because of differences in logging and hauling costs and in timber quality.

APPENDIX C

Detailed Financial Consequences for Study Forests Under the Constant Cost-Constant Stumpage Price Assumption

Table 20.--*Four-decade-average financial effects and employment effects of withdrawing roadless areas and reallocating funds to intensive management*[1], *Bridger-Teton National Forest*

Item	Base programed harvest	Change from base when 50 percent roadless withdrawn	Change from base when 100 percent roadless withdrawn
Harvest (MM bd.ft./yr)	37.4	-12.4	-24.9
Gross revenue ($1 million/yr)	1.9	- .6	-1.2
Cost of roads ($1 million/yr)	NA	- .4	- .9
Cost of cultural treatments ($1 million/yr)	NA	- .1	- .3
Cost of selling timber ($1 million/yr)	NA	- .1	- .1
Net revenue (Item 2-items 3, 4, and 5) ($1 million/yr)	NA	--	+ .1
Payments to counties ($1 million/yr)	.5	- .2	- .3
Present net worth for 10 decades at 5 percent ($1 million)	NA	- .4	- .2
Present net worth for 10 decades at 10 percent ($1 million)	NA	- .2	- .1

NA = not available.
[1]Constant real stumpage prices and real costs were used.

Table 21.--*Four-decade-average financial effects and employment effects of withdrawing roadless areas and reallocating funds to intensive management*[1], *Lolo National Forest*

Item	Base programed harvest	Change from base when 50 percent roadless withdrawn	Change from base when 100 percent roadless withdrawn
Harvest (MM bd.ft./yr)	176	-21	-49
Gross revenue ($1 million/yr)	12.9	-1.5	-3.5
Cost of roads ($1 million/yr)	NA	- .7	-1.5
Cost of cultural treatments ($1 million/yr)	NA	- .5	-1.2
Cost of selling timber ($1 million/yr)	NA	- .1	- .3
Net revenue (Item 2-items 3, 4, and 5) ($1 million/yr)	NA	- .2	- .5
Payments to counties ($1 million/yr)	3.2	- .4	- .9
Present net worth for 10 decades at 5 percent ($1 million)	NA	-5.2	-10.7
Present net worth for 10 decades at 10 percent ($1 million)	NA	-2.0	-4.1

NA = not available.
[1]Constant real stumpage prices and real costs were used.

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Enoch F. Bell, K. Norman Johnson, Kent P. Connaughton, and Robert Sassaman.

1979. Roadless area - intensive management trade-offs on the Bridger-Teton and Lolo National Forests. USDA For. Serv. Gen. Tech. Rep. INT-72, 38 p. Intermt For. and Range Exp. Stn., Ogden, Utah 84401.

This study on two national forests of ways to offset losses in timber harvesting resulting from removal of roadless areas from the timber management base revealed few opportunities to do so. Removal of roadless areas also resulted in decreases in present net worth, in employment, in opportunities for mineral development, in dispersed recreation related to roads, and in forage production in the roadless areas. When the roadless areas were reserved from timber harvest, major improvements on both forests were projected in water quality, in soil stability, in fish and wildlife populations, and in dispersed recreation opportunities away from roads.

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The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 250 million acres, or 90 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University

Reno, Nevada (in cooperation with the University of Nevada)

SURFACE ENVIRONMENT & MINING
SEAM
USDA FOREST SERVICE PROGRAM

USER GUIDE to SOCIOLOGY AND ECONOMICS

Mining and Reclamation in the West

U.S.D.A. FOREST SERVICE
GENERAL TECHNICAL REPORT INT-73
INTERMOUNTAIN FOREST AND RANGE
EXPERIMENT STATION
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

USDA Forest Service
General Technical Report INT-73
January 1980

USER GUIDE TO SOCIOLOGY AND ECONOMICS

MINING AND RECLAMATION IN THE WEST

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401

RESEARCH SUMMARY

The sociologist and economist working on a forest where mining developments are occurring either in or near it must be aware of the potential impacts of mining on the economy and cultures surrounding the forest, and hence, on the management of that forest. This guide covers major points of concern to the sociologist and economist involved in mitigating the adverse effects of such minerals developments, including: land-management planning, issue identification and resolution, sociologic and economic tools for land managers, and role statements for the economist and sociologist in the context of minerals developments.

Information includes supporting graphic material, notes on additional sources of information, a glossary, and an index.

ACKNOWLEDGMENTS

The contents of this guide are based on presentations and discussions during the Surface Environment & Mining (SEAM) sponsored Sociology and Economics Workshop, May 8-9, 1979, Winter Park, Colorado. Credit is due all attendees and presenters for their input. Those who attended are listed in appendix B. In addition, major contributors are listed under chapter titles as appropriate.

A special note of thanks is extended to Gary H. Elsner, Lyle Gomm, Terry G. Solberg, and Ed Thor, members of the cadre which planned the workshop. The workshop program coordinator was Edwin R. Browning (SEAM) and the technical adviser was Fred Wagstaff (SEAM).

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INTRODUCTION

MINERAL AND NONMINERAL RESOURCES

An adequate, reliable supply of minerals is essential to the economy and security of the United States, since minerals provide the physical basis for almost all activities of U.S. citizens. While imports can satisfy an important part of the country's minerals demand, they make the U.S. vulnerable to the economic and political decisions of foreign countries. Thus, the mineral deposits within the U.S. are a most important source of this nation's supply.

A substantial portion of the domestic minerals supply presently comes from lands managed by the Federal Government. Federal lands contain a majority of the metallic minerals, as well as major resources of coal, oil shale, geothermal steam, uranium, and oil and gas. These same Federal lands, however, also contain valuable nonmineral resources, including timber, forage, water, wildlife, scenic landforms, and wilderness. The Government's holdings of such resources are now among the most significant in the world.

While it is clearly in the national interest to provide for the identification and production of the mineral resources on Federal land, it is also necessary to provide for a sustained high-level output of the various renewable resources on that land. Thus, the demand for mineral development must be balanced against the demand for renewable resources and the land-management agency's responsibility to reasonably protect the environment and communities affected by mineral-related operations.

MINERALS IN THE LAND-MANAGEMENT PLANNING PROCESS

The Forest Service, as one of the agencies responsible for Federal land management, has a relatively sophisticated planning program for the management of nonmineral resources on land under its jurisdiction. Historically, however, the Forest Service's land-management and planning systems have treated minerals as a distinct category outside of the mainstream of the land-management planning process. There are two basic reasons for this separation:

1. The mining and mineral leasing laws have tended to make mineral activity the preferred use on any Federal land open to such activity. The thinking has been that on lands open to mineral activity, mineral development will generally override the designated primary nonmineral uses.

2. Planning for use of the mineral and nonmineral resources is complicated considerably by the difficulties of identifying and estimating the value of mineral resources. Mineral resources can be found only through costly and risky exploration. Therefore, land-management planning has tended to concentrate, at least until a mineral discovery is made, on the surface resource potential of the land.

The long-standing premise that mineral activity is always the most valuable use of a tract of land is increasingly being challenged. Many mineral deposits being discovered today are of lower grade, located at greater depths, and are therefore more expensive to find and mine than the high grade deposits formerly developed. Another significant factor is that nonmineral surface resources are now also considered to be scarce, and their value has increased accordingly.

Hence, when all the mineral and nonmineral values are weighed for a particular proposal at a specific location, the value of the mineral resources may be outweighed by the value of the nonmineral resources. The process of weighing values usually occurs in an Environmental Assessment required by the National Environmental Policy Act of 1969 (NEPA) (P. L. 91-190), and is basic to determining the proper mix of uses for any given land area.

Given this situation of mineral and non-

mineral values on the same tract of Federal land, decisions as to the proper use of a particular tract of land will always involve balancing the values of mineral and nonmineral resources. If this balancing is to be done in a reasonable manner, adequate information on and analysis of all values are needed.

BACKGROUND: THE FORMATION AND MISSION OF SEAM

Realizing the complexity of such decisions, in 1973, the Forest Service chartered the Surface Environment and Mining program (SEAM) to coordinate research, development, and application related to land and people impacts resulting from minerals exploration and development in the West. From 1973 to 1979, SEAM sponsored more than 150 research and development projects. Together, the projects have greatly added to the body of knowledge surrounding the management of land in mineralized areas. (For purposes of this discussion, mineralized areas are defined as those areas that have some potential for mining.)

To get this knowledge to the specialists in the field in a form they could readily use, SEAM brought together researchers and users from industry, Federal agencies, and the academic community to share their practical knowledge and study results in a series of workshops. The information presented at these workshops is organized into five user guides. Each guide focuses on a specific discipline involved in resource management related to mineral activities and is written for specialists in these disciplines. The guides will also be of use to land managers, land planners, and other specialists, since many activities related to minerals-area management demand that a variety of skills be applied to achieve an integrated approach.

In addition to the User Guide to Sociology and Economics, guides have been written for vegetation, soils, hydrology, and engineering. Cross-referencing among these guides is provided in the index. A handbook for minerals specialists has also been written. A handbook for land managers will provide a general overview of administrative considerations surrounding mineral commodities commonly explored for and developed on national forest lands administered by the Forest Service. Concurrent with the development of the SEAM user guides, a USDA handbook on visual management related to mining and reclamation, entitled "Mining," is in press as volume 2 of the National Forest Landscape Management Series. A guide for the wildlife specialty is also planned. All guides will be updated periodically to keep them current with research findings.

The purpose of the guides is to help specialists more clearly understand their role in mineral exploration and development activities by outlining some of the major concepts they can use to insure that such activities integrate with land-management plans; that impacts are mitigated to a reasonable degree; and that reclamation meets state-of-the-art performance and cost/benefit standards. Perhaps by using these guides as a common starting point, those involved in minerals management can more easily work together toward achieving these common goals: (1) appropriate consideration of mineral values in land-management planning; (2) protection of surface resources during mining activities; (3) reclamation of surface-mined land to a productive use; and (4) mitigation of the adverse social/economic effects resulting from minerals development.

SOCIOLOGY AND ECONOMICS IN MINERALS ACTIVITIES

Of course, the Forest Service emphasizes that the integration of *all* resource uses is vital to the proper management of NFS lands—and here the skills of the sociologist and economist can be used to advantage. But perhaps nowhere more than in the case of minerals developments can social and economic skills aid the land manager. Beyond the obvious task of placing dollar values on mineral deposits located on NFS lands, the concerns and demands of the people living in the vicinity of a large-scale mining development must be considered by the area's public-land managers. The sociologist and economist can play a crucial role in these situations as they work to:

- Provide an approach to predicting society/forest management interrelationships;
- Integrate this model into forest planning and decisionmaking;

• Give the approach meaning to district rangers and other on-the-ground personnel for day-to-day practical use.

This guide will discuss some of the concepts that can be used to achieve these goals.

HOW TO USE THIS GUIDE

The roles of the Forest Service sociologist and economist are illustrated in table 1, "Stages of Mineral Exploration and Development Activities," and table 2, "Roles of Forest Service Specialists in Minerals Activities," which follow this introduction. As you will note, the Forest Service economist and sociologist can provide expertise in predicting social and economic effects resulting from mining when the operating plan is submitted—long before mining gets underway. Then, during mining and reclamation stages, they will monitor and record any changes so that adjustments in the management plan can be made, if necessary, to respond to these changes. In this way, the effects of the development will be managed in a proactive, rather than reactive mode. In other words, rather than reacting to crises, the sociologist and economist will be part of the forest's interdisciplinary (ID) team from the time land-management planning begins. Then, if and when mineral activities occur, the team will have foreseen potential problems and will have determined general objectives in advance.

The first chapter of this book will look at the role of the ID team both in land-management planning and in site-specific operational planning for mineral activities on National Forest System lands. The importance of the ID team in integrating both mineral and nonmineral values for the decisionmaker cannot be overemphasized. The interdisciplinary approach to planning is uniquely suited to giving the best available assessment of the spectrum of opportunities and problems of managing surface and human resources that may be affected by mineral-related operations and the requirements needed for reasonable protection of nonmineral resources. Soils, vegetation, hydrology, topography, geology, wildlife, climate, and social and economic information are some of the factors that must be considered by the ID team. Such land management and planning must always proceed on the basis of existing information. In the case of mineral resources, this will almost always be difficult because the mineral resources are hidden beneath the surface and information is provided in increments as exploration proceeds. And, of course, human values and concerns are always difficult to interpret. One of the principal goals of Federal land management, therefore, should be to improve such management by obtaining better mineral resource information and integrating it into the decisionmaking process.

When using this guide, the reader should keep in mind that, for the most part, the information is concerned with concepts. While specific costs and physical and legal constraints are a crucial part of the planning process, discussion of these aspects is limited here.

One final note: Social and economic skills are as much an art as a science. To clarify specific points or to keep up with new developments, readers are urged to contact the workshop participants who contributed to this guide.

Additional Information:

For more information on the mining process, refer to "Anatomy of a Mine," USDA For. Serv. Gen. Tech. Rep. INT-35, 1977. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Table 1. — *Stages of mineral exploration and development activities*[1]

Prospecting	Exploration	Feasibility studies/operating plan
A. Administrative Action No administrative action required; however, some evidence of mineralization or a hunch	A. Administrative Action Permit/Lease Notice of intent from miner (for certain commodities, may also serve as operating plan if there is minimal surface disturbance) Exploration license EA may be necessary See Handbook for Land Managers (in press) for variation within commodities	A. Administrative Action Submission of necessary permits (EA, EIS etc.) and operating plan—see Handbook for Land Managers (in press) for variati within commodities
B. Activities Literature search Geological inference Evaluation of existing data Research on rights to land/ minerals	B. Activities More intensive literature search Access road construction On-site testing and evaluation of data—geological, geochemical, geophysical, drilling, sampling, shaft sinking Seismic activity Acquiring land/mineral rights Rehabilitation of exploration impacts Environmental and socioeconomic studies	B. Activities Feasibility studies Grade and size of deposit Cost of mining and rehabilitation Market Fiscal Technical studies—mine design Environmental and socioeconomic studie (if not done during exploration) Decision to proceed with development Preparation of operating plan including rehabilitation program and end use Ordering of equipment
C. Environmental Impacts Minimal, if any	C. Environmental Impacts Roads Drill holes Drill pads Dozer holes Exploration camps	C. Environmental Impacts Generally none at this stage
D. Tasks for the Economist Economic base study: Monitor factors which affect supply and demand for minerals Make forecasts of supply and demand Predict probability	D. Tasks for the Economist Economic impacts: Analyze costs and benefits of alternative exploration methods Participate with the sociologist in identification of existing and emerging issues	D. Tasks for the Economist Economic analyses: Provide expertise in environmental analysis process: issue identification decision criteria cost/benefit analysis of alternatives tradeoff and opportunity cost evaluations Analyze effects of development on: demand for surface resources human behavioral patterns community economics
E. Tasks for the Sociologist Sociological base study: Identify the basic social/ cultural descriptors of the affected communities Note current trends	E. Tasks for the Sociologist Social impact analysis and planning: Assist in structuring public involvement plan for appropriate: issue identification issue analysis mitigation action Identify critical trigger points from a social perspective	E. Tasks for the Sociologist Social impact analysis: Provide expertise in environmental analysis process: decision criteria issue identification Analyze effects of development on the cultural and political community Consider effects of alternative plans on social well being

[1] The various phases have considerable overlap. The material provided for each phase is illustrative, not complete, and conside variation is found by commodity. The existence of a forest plan is assumed. Tasks (D and E) are primarily input fr land-management agency's economist or sociologist. For purposes of discussion, the terms reclamation and rehabilitation are interchangeably, and mining includes oil and gas activities.

Development[2]	Mining/reclamation	Postmining
Administrative Action Approval of necessary operating plan	A. Administrative Action No administrative action required. Mining overlaps with development and reclamation overlaps with mining; reclamation of previously mined areas occurs concurrently with new mining as stipulated in operating plan Any changes in operating plan	A. Administrative Action Release of reclamation bond
Activities Securing of financing More extensive testing and definition of the mineral Construction of transportation routes and utilities Construction of mine and processing plant (facilities, water supply, etc.) Construction of waste deposits Continued evaluation of data Change mining plan if necessary	B. Activities Extraction of mineral Processing of mineral Depositing wastes Operation of transportation systems Rehabilitation Monitoring for any changes in biological and physical environment Amend mining and rehabilitation plan if necessary	B. Activities Surface owner manages land after bond release Monitoring for any changes in biological and physical environment Management and maintenance for end-use objective
Environmental Impacts Mine Processing plant Waste dumps Transportation and access routes Utilities Increased population resulting from construction	C. Environmental Impacts Impacts directly related to operational aspects of mining; impacts are strongly affected by commodity mined and type of operation	C. Environmental Impacts Directly related to management and maintenance activities
Tasks for the Economist Monitoring: Record costs Monitor economic changes	D. Tasks for the Economist Monitoring: Record costs Monitor economic changes	D. Tasks for the Economist Analysis of results and development of new model: Monitor to determine accuracy of predictions for future use
Tasks for the Sociologist Monitoring: Record changes Identify areas of individual or group stress relating to mineral activity and make recommendations to mitigate effects	E. Tasks for the Sociologist Monitoring: Record changes	E. Tasks for the Sociologist Monitoring: Analyze results and develop new model and base study Monitor and record critical changes to establish new baseline situation

[2] Development is herein defined as the phase which begins after the right to mine has been established.

Table 2.—*Roles of Forest Service specialists in minerals activities*

	Prospecting	Exploration	Feasibility studies/operating plan
Vegetation specialist	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in vegetation aspects of environmental studies	Review adequacy of operating plan for: Reclamation program — species selection plant materials site preparation planting methods cultural treatments Monitoring/retreatment program for vegetation Vegetation aspects of end use
Soils scientist	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in soils aspects of environmental studies Review soils inventory progress in the the mineralized areas; if needed, recommend timely completion or upgrading	Review adequacy of operating plan for: Reclamation Program— soils surveys storage area selection materials handling plans spoils analysis plan spoils treatments spoils surfacing and erosion control Monitoring/retreatment program for soils Soils aspects of end use
Hydrologist	Establish baseline water-quality monitoring as needed according to plan	Review of plans to reclaim land impacted by exploration Review and assist in hydrologic aspects of environmental studies	Review adequacy of operating plan for: Hydrologic considerations— surface water subsurface water snow management roads impoundments mine drainage Hydrologic aspects of end use
Engineer	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in engineering aspects of environmental studies	Review adequacy of operating plan for: Engineering considerations— air pollution transportation facilities surface-mine facilities mine-waste disposal embankments tailings dams and impoundments subsidence Engineering aspects of end use
Economist	Monitor factors which affect supply and demand for minerals Make forecasts of supply and demand Predict probability	Analyze costs and benefits of alternative exploration methods Participate with the sociologist in identification of existing and emerging issues	Provide expertise in environmental analysis process: issue identification decision criteria cost/benefit analysis of alternatives tradeoff and opportunity-cost evaluation Analyze effects of development on: demand for surface resources human behavioral patterns community economics
Sociologist	Identify the basic social/cultural descriptors of the affected communities Note current trends	Assist in structuring public involvement plan for appropriate: issue identification issue analysis mitigation action Identify critical trigger points from a social perspective	Provide expertise in environmental analysis process: decision criteria issue identification Analyze effects of development on the cultural and political community Consider effects of alternative plans on social well-being

Development	Mining/reclamation	Postmining
Monitor vegetation impacts and activities for conformance to operating plan. Advise on plan revisions when necessary	Monitor vegetation impacts and activities for conformance to operating plan. Advise on plan revisions when necessary Advise from a vegetation standpoint on release of reclamation bond	Monitor any continued impacts on vegetation Manage vegetation for end-use objective
Monitor impacts on soils Monitor soils-related activites for conformance to operating plan. Advise on plan revisions when necessary	Monitor soils impacts and activities for conformance to operating plan. Advise on plan revisions when necessary Advise from a soils standpoint on release of reclamation bond	Monitor any continued impacts on soils Manage soils for end-use objective
Monitor impacts on hydrology	Monitor impacts on hydrology and hydrologic aspects of rehabilitation program Have hydrologic input into release of reclamation bond	Monitor any continued impacts on hydrology Manage hydrology for end-use objective
Monitor engineering-related activities for conformance to operating plan Advise on plan revisions when necessary	Advise from an engineering standpoint on release of reclamation bond	Monitor any continued impacts from engineered structures Manage structures for end-use objective
Record costs Monitor economic changes	Record costs Monitor economic changes	Mointor to determine accuracy of predictions for future use
Monitor Record changes Identify areas of individual or group stress relating to mineral activity and make recommendations to mitigate effects	Monitor Record changes	Monitor and record critical changes to establish new baseline situation

Chapter 1
LAND-MANAGEMENT PLANNING

Major Contributors: Neal Jensen, W. David Zimmerman, Deen Lundeen

The enactment of the National Forest Management Act (NFMA) of 1976[1] has sharpened the focus on the planning and management of National Forest System (NFS) lands. As directed by the NFMA, greater emphasis must now be placed on public participation in the development, review, and revision of land and resource management plans. Coordination of such plans with State and local units of government and other Federal agencies is required. In addition, national, regional, and local resource goals will be assessed periodically based on supply and demand of renewable resources from public and private forest and rangelands. And, the NFMA requires an interdisciplinary (ID) team approach within the Forest Service in planning for and managing NFS resources.

For the Forest Service sociologist and economist, these new regulations have particular significance. In addition to the likelihood that these scientists will, at some point, be requested by the land manager to participate in the ID team, the skills of the sociologist and economist are particularly relevant to several of the planning actions outlined by the NFMA regulations.

For example, directions for planning and management require that:

1. Planning be driven by and respond to issues.

2. The best available resource data and information be collected, including the views of citizens, special interest groups, and other Federal, State, and local agencies.

3. The synthesis and evaluation of such data and information be carried out utilizing professional and administrative judgments as how to best meet the statutory goals and objectives and achieve the interests and expectations of the public. The economist and sociologist, with their skills in the human behavioral sciences, will be important contributors to this new process.

In particular, the NFMA regulations state that economic analysis of management program alternatives to determine economic consequences be undertaken, and that this economic analysis be done at all appropriate places throughout the planning process. And, NFMA states that the public must be adequately informed throughout the planning process and that procedures for public participation must be documented.

To familiarize the social scientist with the new framework in which he will play a role, this chapter will discuss the planning process as outlined by the NFMA regulations; the interdisciplinary team; and the new operational mode that has evolved out of these changes. To illustrate the role the sociologist and economist could play in these areas, examples of how their skills might be used are provided in several places. A more detailed discussion of their roles, especially when a mineral development is having an impact on the forest or surrounding community, will follow later in this guide.

THE PLANNING PROCESS

The NFMA regulations spell out 10 planning actions that must be followed during the planning process, with the note that these activities are a general framework, and additional steps may have to be added to link these elements together. The first four planning actions are a continuous process—they take place all the time and not in any particular order. The last six ac-

[1] U.S. Laws, Statutes, etc. Public Law 94-588. [S. 075], Oct. 22, 1976. National Forest Management Act of 1976. In United States code congressional and administrative news. 94th Congr. 2d sess., 1976 Vol. 2, p. 949-2963. West Publ. Co., St. Paul, Minn. [1976.]

tions are sequential activities that take place whenever a change or amendment to the plan is needed. The planning actions are listed in figure 1. An explanation of each action follows:

• **Planning Action 1—Identification of issues, management concerns, and opportunities.**

To plan and manage effectively, the land manager must know what he is to manage f This direction will come from an evaluation public issues, management concerns, and i source use and development opportunities.

As defined in the NFMA regulations, a pub issue is a subject or question of widespread pu lic interest relating to management of Natior Forest System lands and identified through pu

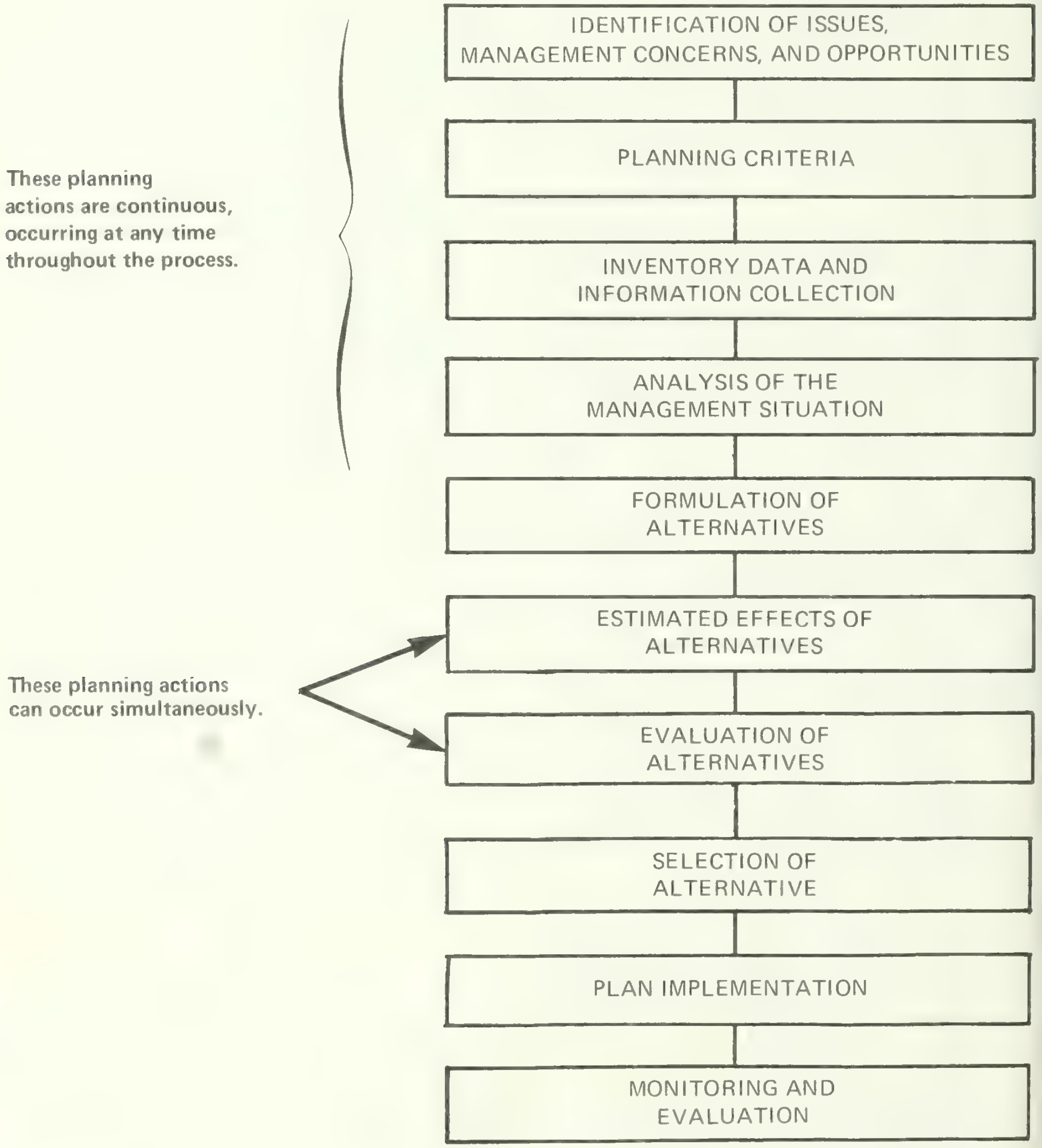

Figure 1. Ten planning actions in the planning process.

lic participation. A management concern is an issue or problem requiring resolution, or condition constraining management practices, identified by the interdisciplinary team.

This first planning action in the process is a continuous activity; Forest Service personnel will continually monitor emerging issues, concerns, and opportunities, their importance, how they can be resolved, and what responsibility or authority the Forest Service has for resolving them.

Public participation and coordination with other Federal agencies, States, and local governments throughout the planning process will be essential in identifying, evaluating, and resolving public issues. In other words, issues become the driver of the planning process.

The sociologist, with skills in understanding the interactions of human groups, can be a primary identifier and analyst of public issues. The economist, with skills in understanding how economic factors influence the way people relate to their surroundings, can help analyze the source of issues and detect emerging issues.

(Issue identification and resolution will be covered in more detail in chapter 2.)

• **Planning Action 2—Planning criteria.**

Two types of planning criteria are involved in this step:

1. **Decision criteria.** From an evaluation of issues, concerns, and program requirements from the regional or national level, the planning team will develop a set of goals and objectives that will resolve the issues, concerns, and requirements. These goals and objectives become the criteria that the planning process will try to meet; objectives will also provide guidance for evaluation and selection of alternatives later on in the process.

2. **Process criteria.** This information provides a framework for going through the planning process. Process criteria can include data and information requirements, analysis requirements, and the feasibility of management practices.

The sociologist can aid in determining whether these decision criteria will satisfy public concerns. The economist can aid in establishing goals and objectives which are useful decision criteria and can evaluate the objectives from an economic standpoint: costs and benefits involved, budgeting required, etc.

• **Planning Action 3—Inventory data and information collection.**

Collection of current, up-to-date information comes at this point in the planning process because data should only be gathered to answer questions raised by the issues and concerns and to satisfy the goals set in the planning criteria. Existing information will be used whenever possible. This is in contrast to the traditional practice of collecting data first and then trying to interpret what has been collected. Under the new planning process, the ID team will identify what data are needed, and then it becomes the responsibility of the staff specialists to gather these data and bring them back to the team. The information and data collection system used must also be consistent with monitoring and evaluation procedures so that these two steps tie together.

The sociologist and economist will supply and interpret sociological and economic data in consultation with the ID team.

• **Planning Action 4—Analysis of the management situation.**

All of the preceding planning actions—which are continuing types of activities—are brought together at this point. The issues and concerns are summarized and directed toward this action, data are synthesized into information, and the information and concerns are analyzed. The primary purpose of this step is to assess the ability of the area under planning to supply goods and services in response to society's demand for those goods and services. The analysis will display the capability and suitability of the forest to supply outputs and uses, and will project demands for the outputs or uses over time. It will identify any special conditions or situations which involve hazards to the resources in the planning area and their relationship to proposed and possible actions being considered.

Specifically this analysis will determine:

• Ranges of various goods, services, and uses that are feasible under existing conditions at various levels of management intensity.

• Projections of demand, using the best available techniques, with both price and nonprice information. These projections, in conjunction with supply/cost information, will be used to evaluate the level of goods and services that maximizes public benefits. To the extent possi-

ble, demand will be assessed as a price/quantity relationship.

• Potential to resolve public issues and management concerns.

• Technical and economic feasibility of providing the levels of goods, services, and uses resulting from assigned goals and objectives.

• The need, as a result of this analysis, to establish or change management direction.

The overall final objective of this analysis is to determine whether or not the existing plan is adequate or whether changes are needed. If the existing plan is adequate, the land manager can continue to follow it, keeping in motion the first four actions of the planning process. If the plan is not adequate, the next six planning actions should be followed sequentially.

The economist can apply his skills to the economic analyses required in this step. For example, he can determine the relationship between resource outputs and services. The sociologist can aid in determining if present management is resolving public issues and management concerns.

• Planning Action 5—Formulation of alternatives.

A reasonable range of practical alternatives will be formulated by the ID team. Alternatives will be described in draft and final Environmental Impact Statements. The purpose of the management practices proposed will be clearly stated for each alternative.

Alternatives will display a range of possible outputs of resources. Beginning with a present situation, or a no-action type of alternative, the team will develop various types of alternatives that will address the major issues and concerns identified earlier in the planning process, and will also meet national or regional program requirements. Each alternative must be capable of being achieved and must state the conditions and uses that will result, the goods and services to be produced, and the timing and flow of those goods and services. Each alternative must also specify the resource management standards and guidelines that will be put into effect with that alternative.

The economist and sociologist can help structure the alternatives to meet social/economic decision criteria and can identify the social and economic concerns addressed by each alterna tive.

• Planning Action 6—Estimated effects of a ternatives.

The ID team will estimate and display th physical, geological, economic, and social effect of implementing each alternative. These will ir clude the following:

• Expected outputs, both for market an nonmarket types of goods or resources.

• The relationship between the local, short term uses and long-term productivity.

• Adverse environmental effects that canno be avoided.

• Resource commitments that are irreversibl

• Direct and indirect benefits and costs. Thi will require determining expected administrativ costs, real dollar value of outputs, real dolla investments and operating costs, which alterna tives come nearest to maximizing the net publi benefits, and the economic effects of the alte natives. The effects of the alternatives on mino ity groups, prime farmlands, wetlands, and floo plains must also be considered.

The sociologist and economist can estimat the social and economic effects of implementin each alternative.

• Planning Action 7—Evaluation of altern tives.

At this point, the decision criteria develope in planning action 2 come back into play. Th land manager will decide which one of the alte natives best meets those criteria. As part of thes criteria, the alternatives must be compared by economic efficiency, distributional aspects, ou puts of goods and services, and protection an enhancement of environmental resources. Th analysis is used to determine whether or not preferred alternative can be identified, and if so, to select the alternative that will be used in th draft Environmental Impact Statement.

Again, the sociologist and economist ca evaluate differences in the social and economi aspects of the alternatives.

• Planning Action 8—Selection of alternative

After publication of the draft Environmenta Impact Statement (EIS), the ID team will evalu ate public comments and, as necessary, revis the appropriate alternative. The responsible o

ficial will recommend a selected alternative for the final EIS, using the decision criteria that have been developed, and will document the benefits of choosing this alternative.

The sociologist can aid in evaluating public comments. The economist can apply his skills to comparing economic aspects of the decision criteria to the selected alternative.

- **Planning Action 9—Plan implementation.**

During the implementation of each plan, the responsible official will assure that annual program proposals and implemented projects are in compliance with the plan. He will also make sure that program budget allocations meet the objectives and are consistent with all applicable standards and guidelines specified in the plan.

The economist can play a significant role in program budget proposals.

- **Planning Action 10—Monitoring and evaluation.**

At intervals established in the plan, management practices will be evaluated on a sample basis to determine how well objectives have been met and how closely management standards and guidelines have been applied. The results of monitoring and evaluation will be used to analyze the management situation and make revisions in the plan as necessary.

The sociologist and the economist can be primary identifiers of the need for revisions in the plan to respond to changing social and/or economic conditions.

Additional Information:

Much of the information in this chapter was based on the Federal Register, Vol. 44, No. 181, Monday, September 17, 1979, "National Forest System Land and Resources Management Planning (as corrected in the Federal Register of September 19, 1979)," USDA Forest Service (36 CFR Part 219).

A computer tool has been developed to aid the ID team in planning program allocations. Called ADVENT, this computer program can tie multiyear projects developed for different management option levels of funding to the goals and objectives of the Resources Planning Act. Targets are produced based on outputs and activities within dollar and manpower constraints. For more information on ADVENT, contact Management Sciences Staff, Pacific Southwest For. and Range Exp. Stn., Berkeley, Calif.

THE INTERDISCIPLINARY TEAM

A key element in the new planning approach is the interdisciplinary (ID) team. The development of the ID team is a direct result of the NFMA and the National Environmental Policy Act (NEPA)[2] of 1969. Both Acts require specialists to work as a team in developing the forest plan. This is in contrast to using a functional or multidisciplinary approach in which the separate specialists gather information and then bring it to the land manager or planner, who integrates the various points of view.

Specifically, the NFMA regulations state that the ID team will represent two or more areas of specialized technical knowledge about natural resource management applicable to the area under planning, and that the team will be involved in a continuous planning process. It also directs the team to consider problems collectively rather than to separate them along disciplinary lines. The regulations, however, do not state what types of disciplines should be represented on this team. Instead, the line officer responsible for the planning process will choose the team, based on the types of resources and issues that must be considered.

Some members of the team will be permanent. This nucleus will coordinate and lead the planning process. But the team will also recruit members on an interim basis to address specific issues. Their length of stay on the team could vary from a few hours to several months. Thus, theoretically, every specialist in the organization is a potential ID team member, with a core group of people making overall decisions on who

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[2]U.S. Laws, Statutes, etc. Public Law 91-190. [S. 1075], Jan. 1, 1970. National Environmental Policy Act of 1969. An act to establish a national policy for the environment, to provide for the establishment of a Council on Environmental Quality, and for other purposes. In its United States statutes at large. 1969. Vol. 83, p. 852-856. U.S. Gov. Print. Off., Washington, D.C. 1970. [42 U.S.C. 4321, 433-4335, 4341-4347.]

should be brought in to resolve certain issues and concerns.

Obviously, such an approach makes the planning job much more complex. Individuals representing various disciplines will have to cooperate with other specialists, as the team works in a combined effort toward meeting the objectives of the group's decision criteria. Thus, team building efforts may be needed to help the group learn how to work more effectively together.

One way to look at how the ID team will fit into the overall national forest management system is represented in figure 2. As shown in the chart, the forest system is divided into three parts as follows:

1. **The management team.** The management team is the decisionmaking body. The line officer and other members of his primary staff, such as district rangers on the forest level, or the regional forester and his primary staff at a regional level, are part of this team.

2. **The interdisciplinary planning team.** This team is responsible for all the planning within an administrative unit. The ID team's role can be broken down into two main categories: planning operations, and planning information and analysis. Planning operations can be considered the core team that keeps all planning activities on track. The six responsibilities under planning operations include:

- ID team leadership.
- Planning system support. This can include informal information systems, which could be anything from a file cabinet to an elaborate computer data retrieval bank, and analytical systems, which again can range from simple manual mathematical procedures to a complex computer model.
- Coordination, both internal within the agency, and external.
- Legal assistance.
- Document preparation. Preparation of the plans, the environmental statements, budget proposals, planning process documentation, etc.
- Administrative support. Personnel, fiscal, and operations support.

The second role of the ID team includes planning and analysis of the physical, biological, social and economic, and management systems. In other words, the planning operations part of the ID team leads and coordinates the team, while the planning information and analysis pa of the team provides the studies that are neede to develop the forest plan.

3. **Ongoing program management.** This thir part of the forest system is responsible for in plementing the plans. It is the operational pa of the system and takes care of all programs an projects, including administration, monitorin and enforcement.

NEW OPERATIONAL MODE

The sum of the NFMA regulations points to new mode of operation for Forest Servic specialists, whether they are planners, soci ologists, economists, or hydrologists. Th following discussion contrasts the new mod with the historic mode of operation in th Forest Service, with the qualification that th old mode may have many valuable aspects an the new mode may have weaknesses. In oth words, the contrast is not meant to set on mode up as categorically superior to the othe but simply to show the new direction of NF planning and management in the years ahead– direction that will affect all Forest Servic personnel.

1. From multidisciplinary to interdisciplinar Rather than each specialist concerning him self only with his discipline, the new mod of operation calls for members of the ID team to integrate their disciplines into the planning pro cess.

2. From a data-oriented approach to an issu oriented approach. Rather than specialists co lecting data to add to the knowledge surroun ing their discipline, data collection is now di rected by the issues and concerns being ad dressed.

3. From an emphasis on strictly gatherin facts to an emphasis on evaluation and the pr dictive capability of the specialist. In oth words, what does the specialist know and wh can he infer and predict from this knowledg that will aid in formulating alternative manag ment directions?

4. From planning as a report to planning as process. In the new mode of operation, plannin will be an ongoing, continuous process and w be part of the management approach, not simp

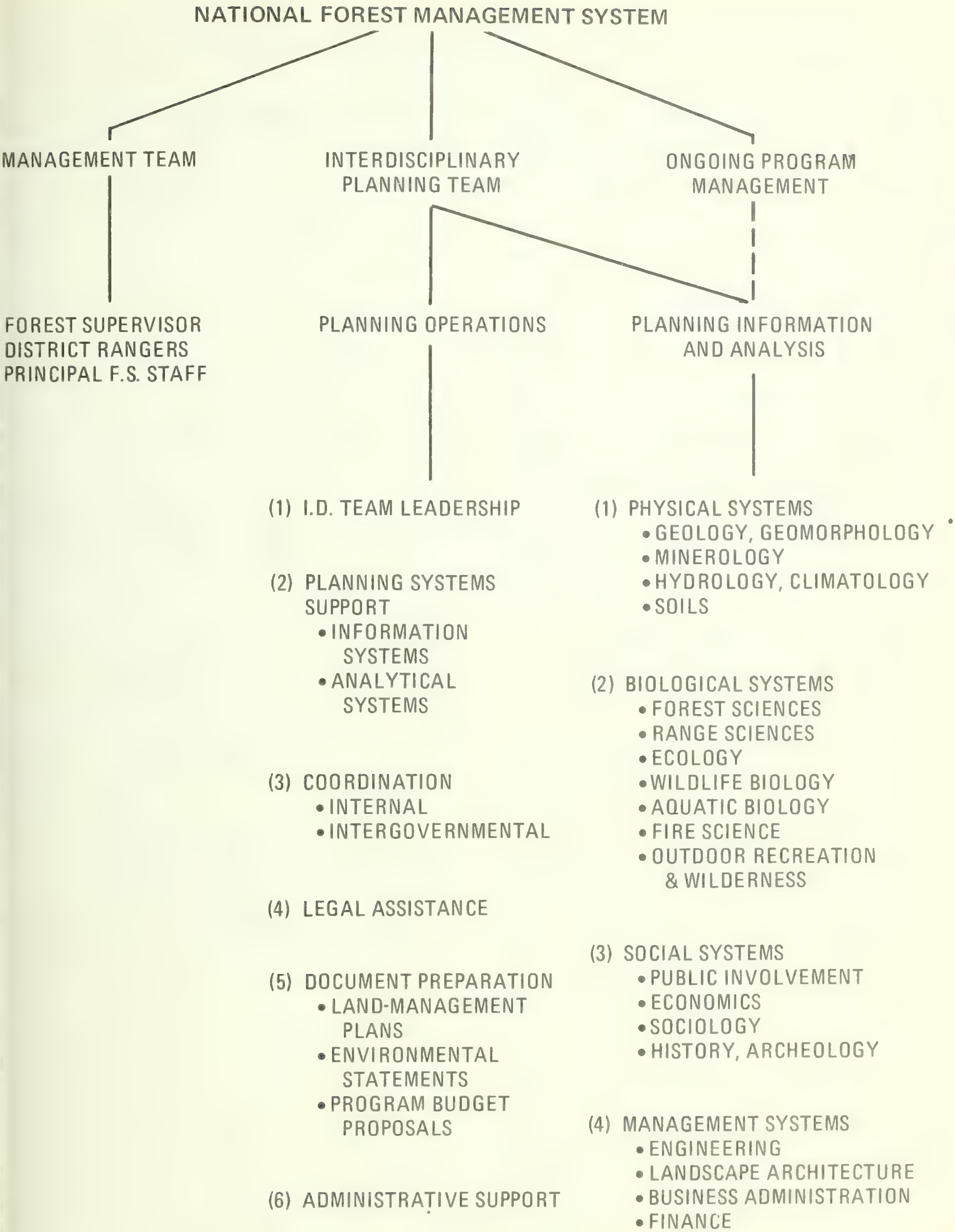


Figure 2. The interdisciplinary team in relation to the national forest management system.

a document. The ID team leader will facilitate and manage the planning process for the manager.

5. From a concept of public involvement that focuses on explaining plans to the public to a concept of public involvement as a continuing process in developing plans.

6. From an approach where disagreement among specialists comes late in the planning process when the specialists bring in their data to an approach where disagreement comes early in the process and precedes data collection. The ID team can discuss potential disagreements at the front of the planning process during identification of issues and decision criteria.

7. From permanent planning team membership to flexible team membership. The core planning team may be permanent, but it will draw in specialists to address various issues and concerns. In other words, a small group of people at the nucleus of the team will call upon a broad array of specialists who are geared towards issue-oriented planning, rather than ha ing the same group of people handle every pla ning aspect.

8. From the planner doing all the planning the planner as facilitator and coordinator of t process.

9. From a discipline orientation to a huma interaction orientation. This is not to imply th the disciplines will be any less needed, but t ability to work on a planning team will be er phasized in the new mode, whereas in the ol the specialists' skills in team work were not co sidered as important.

10. From line decisions coming at the end the plan development to an approach where li decisions are built into the system at key poin throughout the planning process. This approa should aid in keeping the plan effective and e ficient.

11. From planning as a mechanism to defer or justify management actions to planning as process for determining management actions.

Chapter 2
ISSUE IDENTIFICATION AND RESOLUTION

Chapter Organizer: Fred J. Wagstaff

Major Contributors: James Hagemeier, James Kent, Jo Anne Tremaine, Fred J. Wagstaff

National Forest System lands have always belonged to the public, but because the public's concerns and desires have not always been expressed openly, the land manager was often forced to deal with resources as he thought best. Now, though, the public is recognizing and demanding its right to participate in the land-management process, and, in response, listening to the public's concerns is a major emphasis of the planning regulations set forth in the National Forest Management Act. In fact, the first planning action in the planning process requires the identification of public issues, defined as subjects of "widespread public discussion or interest regarding the management of National Forest System lands."

Once these issues have been identified, they will not only guide the entire planning process, but they will also provide a basis for evaluating the effectiveness of a forest plan. Issues will help determine the goals to set, the areas of management to further analyze, the type and amount of data to collect, and the public participation needed to resolve the issues and complete the plan. Thus, early identification of issues is essential, since all other steps in the planning process are designed to resolve these issues.

Since most public concerns are social and economic ones, the disciplines of sociology and economics should be involved in issue identification from the beginning of the planning process. The sociologist and the economist can help the land manager focus in on public concerns since they are trained in identifying and predicting behavioral patterns and supply/demand trends, and have an ethical commitment to be objective. This skill is especially important when a concern exists about what future reactions to a situation might be.

MINERALS ISSUES

It seems likely that, in the future, the number of public issues demanding Forest Service attention will increase, primarily because there is a growing number of land-based conflicts. For example, the question of outstanding and reserved mineral rights will have a tremendous impact on the management of National Forest System lands, as will the increased demand for surface-area uses. Also, the public is more politically aware, sophisticated and concerned than it was in the past. Thus, it is crucial that the Forest Service consider these concerns at the beginning of the planning process rather than at the end of drawn-out legal procedures. The importance of recognizing public concerns is especially critical when minerals developments are involved. Often, for example, the minerals industry has been accused of abusing the legal rights it has under the General Mining Law[3]; and thus any mining activity will raise concerns with at least some segment of the public. In addition, the nature of mining makes it a highly visible activity. Mining development sometimes brings large population increases in a short period of time to communities that are neither socially nor culturally equipped to deal with such influxes, and the environment surrounding minerals developments can be substantially changed by the activity. Nevertheless, increased minerals development is almost inevitable because of society's increased demand for these products.

During the planning process, then, the land

[3] Act of May 10, 1872. 17 Stat. 91

manager should identify mineralized areas that are, or possibly will be, developed. Then, depending on the type of mineral, the type of mining and processing involved, and the area's current employment needs, potential minerals-related issues should be identified. The sociologist and economist can aid in identifying issues by determining the social, cultural, and political aspects of the area's current population, as well as whether the community's attitude is pro-growth, anti-growth, or a mixture of viewpoints. From this analysis, issues can be better focused on, deliberated, and perhaps even resolved. Guidelines for describing, determining, and resolving issues are discussed in the remainder of this chapter.

IDENTIFYING ISSUES

While it is impossible to eliminate national and regional needs when dealing with issues, issue identification generally focuses on local social and economic concerns, such as whether or not a minerals development will adversely affect an area's tourist economy. To learn about the public's concerns, the land manager should turn to the people of the community—those who are tied by economic, cultural, and physical boundaries to the site of the new development—for help. Forest Service personnel should also be questioned since they too are members of the community and are familiar with the concerns of the local population. Another key element to consider is the viewpoint of the absentee client, such as the urban resident who vacations in the forest, or a mining firm with headquarters in another State.

Basically, two types of networks exist that should be used in identifying issues: the formal and the informal. The formal network includes organized groups, such as recreational vehicle clubs and city councils, while the informal network includes the person in the coffee shop who is not making any requests, but is merely discussing his interests and how he feels the land should be managed.

Public issues can be divided into three stages of development. They are:

• **The emerging issue.** A topic of discussion or activity that may evolve into a demand by th public concerning forest or rangeland resourc or programs.

• **The existing issue.** A direct public demar influencing forest or rangeland resources or pr grams.

• **The disruptive issue.** A direct public d mand, on forest or rangeland resources or pr grams, that is beyond control of the resour manager at a given administrative level. Th type of issue requires immediate management a tention and action. With a disruptive issue, th public may take resource management into i own hands through such actions as tearing dow fences or putting up barricades on national fore lands. Because this type of issue can devel into a crisis situation, management should r spond, as much as possible, to emerging and e isting issues to avoid their becoming disrupti ones. (See fig. 3.)

Any of the above issues can also be co pound issues, which means that they are mul jurisdictional and require action by agencies organizations other than the Forest Service f resolution.

When determining public issues, it is i portant to separate these issues from manag ment concerns. While both items can sometim be interrelated, most management concerns a generated in administrative procedures. The p mary distinguishing factor between the two that unless a concern can be tied to the publ there is no issue; if a public tie exists, regardle of legalities, an issue exists.

To date, complete criteria for issue analy have not been fully developed. Neverthele some guidelines for identifying issues have be established during the lead forests' planning pr cesses. According to these criteria an iss should:

• Have potential or existing conflict.

• Have potential for a change in manageme plans.

• Have an effect on the allocation of r sources.

• Deal with the here and now.

• Require a Forest Service role in resolutio

• Be capable of being written as a questio

• Be verifiable through public involvemer

• Be composed of subissues which are resol able. If the subissues cannot be resolved by th

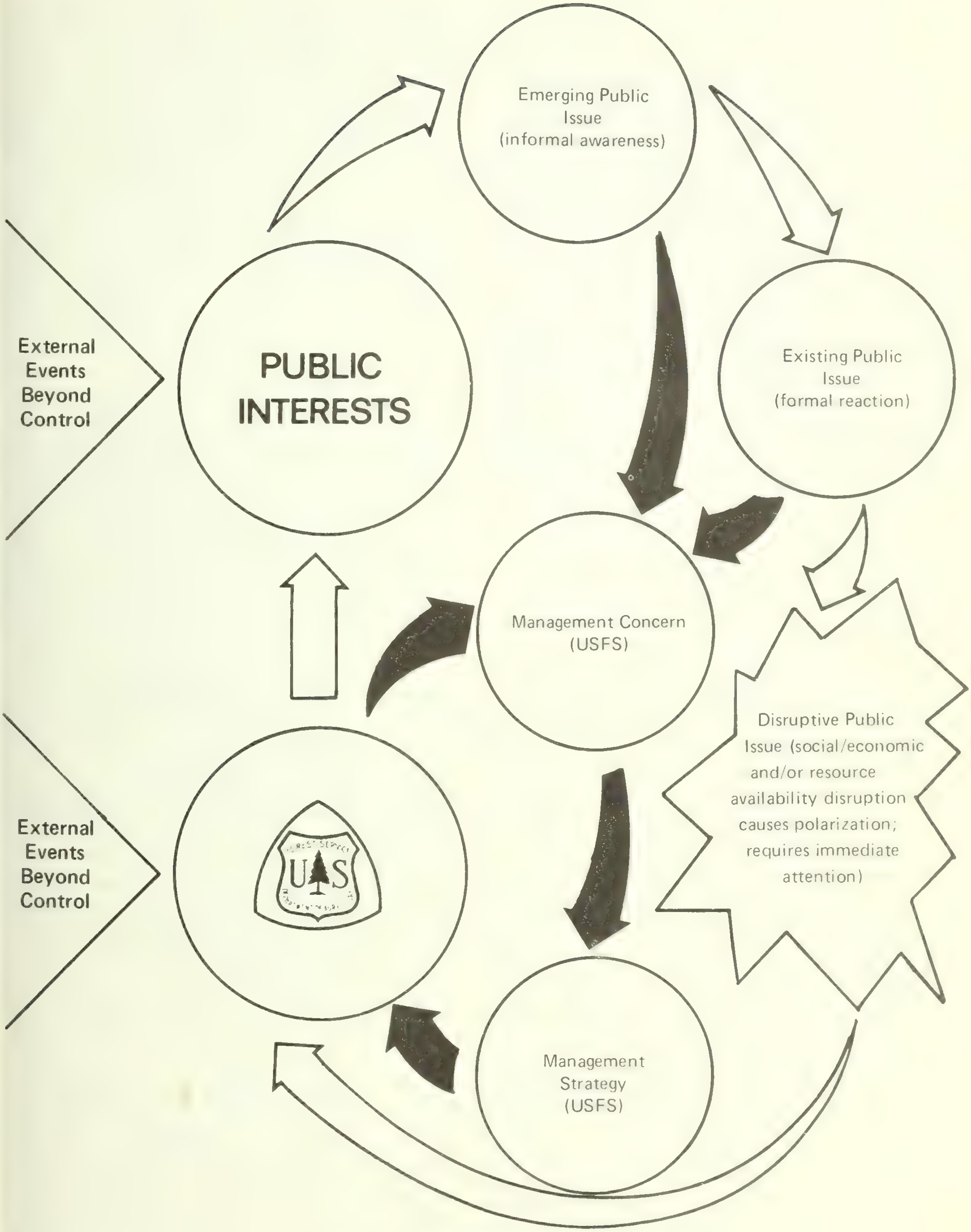


Figure 3. Responsive management system.

Forest Service or another agency or organization, there is no point in including the issue in the forest plan.

One process for determining public concerns was developed during the planning process in the Ottawa National Forest in Michigan. It involves the use of issue papers and direction memorandums (fig. 4). Through informal discussions with the public, Forest Service personnel returned to the public with an issue paper stating what they perceived as the primary concerns. After revising the statement to reflect concerns of this meeting, the Forest Service returned to the public once again for more input, and then produced a final paper that included consensus about which issues should be addressed. Resolving the issues took the form of a direction memorandum, with three different drafts. For the first draft, questions stated by the public in the issue paper were discussed with the ID team, and decision criteria pertinent to answering those questions were determined. Data needs necessary to solve a particular decision criteria were also determined at that time. Then the Forest Service returned to the public to find out whether, in fact, these were the items of concern, whether the decision criteria were appropriate, and whether any other decision criterion should be included. After incorporating this input, a final memorandum was drawn up. This process was the one used to develop the issue paper, and it lent credibility for the alternative formulation and tradeoff analysis stage.

RESOLVING ISSUES

Once an issue or set of issues has been identified, it is necessary to determine whether or not

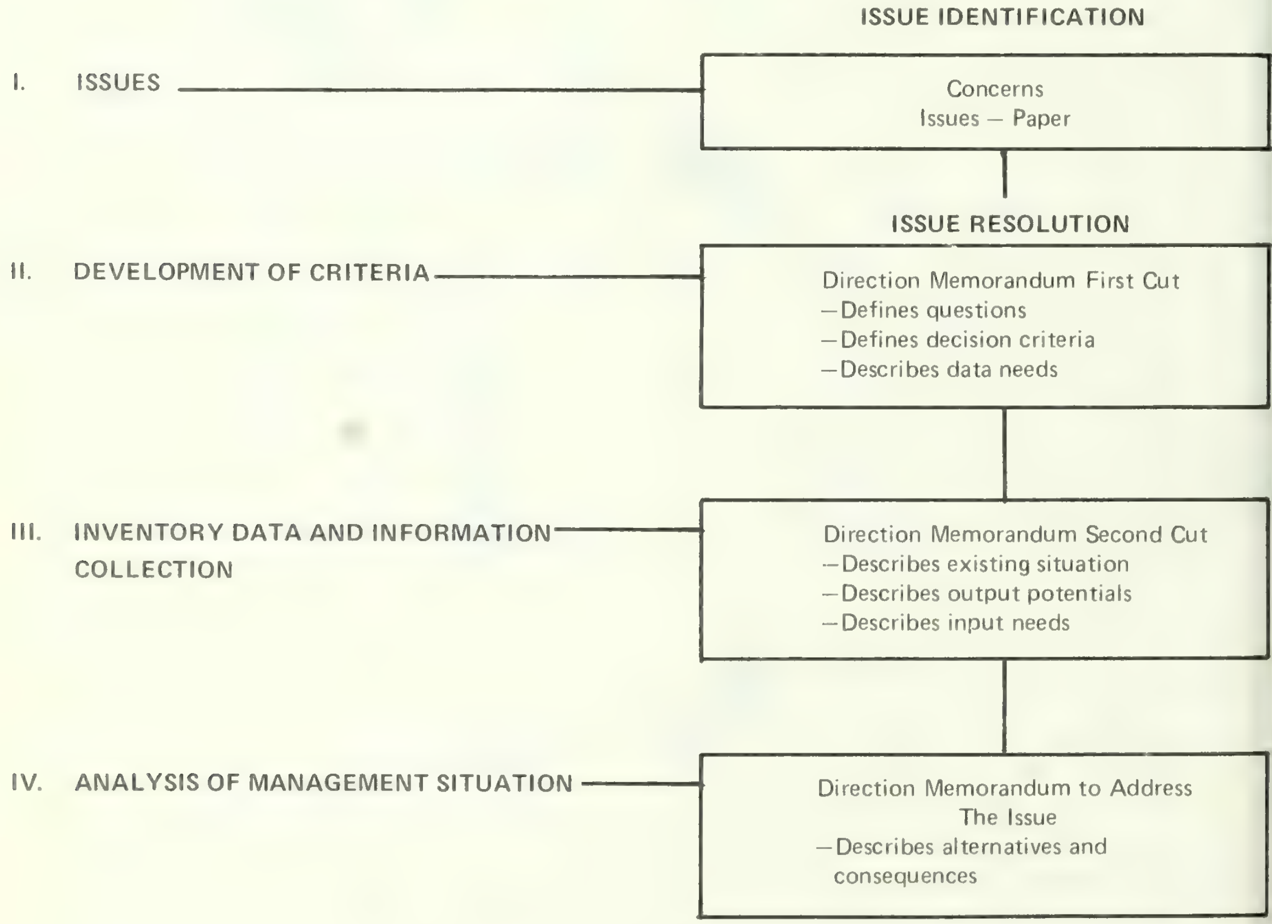


Figure 4. Issue scoping and resolution.

the machinery exists to resolve them. If an Environmental Impact Statement (EIS) containing planning criteria can properly address an issue, those steps should be implemented to resolve the issue. Currently, though, there are no EIS planning criteria, so all issues addressed by the first run of the planning process will require the development of criteria with full-scale public involvement. Then, to resolve identified issues, they should be reduced to specific questions that can be analyzed and answered. A limiting factor approach can be employed to narrow down the large number of questions that might result from a given issue, and only questions critical to resolving the issue should be answered.

Some criteria that might provide a basis for deciding which public issues to consider and which to ignore could include questions such as:

- How well does the issue relate to factors that the Forest Service manager can legitimately influence or directly control?
- How well can the issue be addressed by the Forest Service in terms of minimizing or avoiding social disruption?
- How well can the current budget pay for the cost of resolving this potential issue?
- What potential exists for public participation in the definition and resolution of this issue?

Once the issues have been narrowed down, they should be reviewed in light of Forest Service management goals, including policies, program directives, resource allocation, and performance requirements. Public issues that require immediate Forest Service attention should be distinguished from those that may need attention in the future.

After deciding which issues deserve consideration, the next step is developing a strategy to resolve them. At this point it is necessary to determine the organization or agency that has the authority to deal with each issue. Particularly in the minerals area, the Forest Service by itself often cannot handle the total issue. In administration alone, for example, there is a shared responsibility among the Forest Service, the States, and the Department of Interior for managing mineralized areas. And, if organizations other than the Forest Service are involved, they too must recognize the issue and their responsibility for a share of the resolution. In addition, there are some issues that can best be dealt with at a regional level, rather than at a forest level.

During this stage of the planning process, it will be important for the Forest Service to maintain communication with the public to minimize conflicts arising from issues. In the case of minerals development, this will mean demonstrating what can be done to minimize physical and biological impacts from mining, professionally evaluating social and economic impacts, and describing what the Forest Service can and cannot do to mitigate these impacts. For example, is it possible to resolve these issues or are the costs and side effects beyond the Forest Service's control? If not, what are the alternatives and tradeoffs? Sometimes it will not be possible to resolve all conflicts. But, including the public in the decisionmaking process allows for public understanding of the limitations of the Forest Service's capabilities as well as the demands that arise from other areas of the country on regional and national levels.

ISSUE EXAMPLES

When a proposed minerals development takes place, there are some issues and concerns that generally tend to surface. Often, the public's main concern centers around the question of whether or not mining should take place. This issue, though, is sometimes a false one. For example, in Gunnison County, Colorado, the issue at first appeared to be whether or not AMAX should be allowed to mine the molybdenum deposit under Mount Emmons. This issue was not within the jurisdiction of the Forest Service, because those lands are already patented and AMAX does have the right to enter and mine that particular body of ore. There was, though, a real issue revolving around the mining method. The company proposed a block-caving mining method—which could create potential subsidence—and no one was sure what the surface expression of this mining method would be in the future. Usually when people are concerned about the visual, environmental, and other aspects of landscape modification, an issue will be centered around the mining method.

Then, too, many issues revolve around the

milling process—that is, how will the ore be processed and where? One of the critical elements of milling ore is tailings management, since tailings dams are often sizable structures and many have failed. A series of issues also exists pertaining to reclamation. When is it going to be done, by whom, and for what purpose? More and more often the public is demanding a reclamation plan with a specific end use in mind; however, many State laws currently do not favor objective-oriented reclamation, and, instead, base requirements on native vegetation and original contour.

Another consideration is how the social and economic impacts of minerals development will be dealt with. To address this concern, the sociologist and economist must determine who will feel the impact of minerals development, how great the impact will be, when mitigation will be possible, and who will pay the costs. Strides have been made in requiring those responsible for minerals development to pay for some of the front-end mitigation costs; nevertheless, it is still difficult to determine what the total actual costs will be in the long run.

In a reversal of this concern, mine closings can also emerge as an issue. Although the situation is changing, in the Rocky Mountain area, most communities surrounding National Forest System lands have historically been low-income cultures. Thus, mine closings can have a significant impact on the economies of these communities, and it is necessary to examine the use of resources on forest and adjacent lands in a social context. It might, for instance, be possible to change the entire mode of timber operations so that increased timber operations coincide with mine closings. This would provide jobs for those people who have suitable skills. Should issues result in a change in management objectives, the disciplines of sociology and economics play important roles in proving the validity of these objectives. For example, harvesting timber during different times of the year to meet social goals might require a budget increase, and social/economic data will be vital in lending credibility to such a request.

Of course, issue identification and resolution are not static processes. They require constant monitoring. Over a period of time the physical, social, and economic aspects of areas surrounding Forest System lands will change. Some issues will be resolved, others will fade away, and new ones will emerge. Thus, social/economic concerns will need continuous reevaluation. But, by monitoring public issues, the land manager can insure that his land-use decisions are responsive to the needs and concerns of the public.

Chapter 3

SOCIOLOGIC AND ECONOMIC TOOLS FOR LAND MANAGERS

Chapter Organizer: James Kent

Major Contributors: James Kent, Richard Greiwe, James Hagemeier, Hanna J. Cortner, Julie (Marty) Uhlmann, Diane Hammond

As discussed in chapter 2, listening and responding to the concerns and demands expressed by the public are major stipulations of the NFMA. But even without these regulations, most land managers have realized that listening to the people who use and are concerned about the forest's resources is crucial to good land-management decisionmaking. Traditionally, the land manager has turned to the local community for its input. As a citizen of the community, he has understood what values were important to the people living near the forest and how these values affected the management of the public land under his jurisdiction.

The last decade, however, has seen the job of communicating with the public become increasingly more complex. As the country's population—and its consumption of natural resources—have boomed, demands on public lands have also skyrocketed. Where once a land manager faced a nearly homogeneous community whose interests could be satisfied with one or two resource development programs, today most forests are hit with numerous demands that can range from advocating all-out resource development to insistance on wilderness preservation at any cost.

To understand and manage these "people" pressures, social scientists and land managers have sought new ways to help them incorporate social and economic concerns—the concerns of people—into land-management decisions. This chapter will present three sociological models that have been developed to answer this need. They can be used by the land manager, sociologist, and economist to analyze social impacts and to predict social change as a result of mineral, recreational, or other resource development occurring on or near national forests or national grasslands. These models might be used by Forest Service staff to assess what effect forest planning and management will have on a community. Or, they might be used by a mining company who must include a social impact assessment as part of an Environmental Impact Statement or an Environmental Assessment prior to start up of mining operations on Forest Service land. In this case, the Forest Service sociologist and economist would suggest approaches to such an assessment and would review the results.

The fact that only three models are discussed here is not to imply that they are the best, or the only, models available to the sociologist. Rather, the intent is to illustrate how such models can help the ID team and the land manager to focus on issues—and thus why they are valuable tools in the planning and management of public lands.

THE HUMAN RESOURCE UNIT

One way of systematically looking at a society and the way change affects it is through the concept of the Human Resource Unit (HRU). The concept was developed by the Foundation for Urban and Neighborhood Development (FUND), Denver, Colo., under contract to the USDA Forest Service, SEAM program. The HRU process is currently being tested on several national forests as part of their land-management planning efforts.

The HRU is a concept of geographic decisionmaking that can be implemented by nonsociologists. For example, where a mining development is involved, the HRU will be the local area—the lands and communities—that are most closely intertwined and interrelated with the site of the proposed new development. In other words, an HRU is not an artificial, politically

created area, such as a county or township. Instead, it is the lands and the people tied by economic, cultural, and physical boundaries to the site of the new development. More formally, an HRU can be defined as:

> A geographic area of land that is characterized by particular patterns of cultural lifestyles, economic conditions, and topography. The HRU is used to design management actions that respond to changing social conditions or physical resource uses at the district or forest level.

As a simplified example, an HRU may be a mountain valley where the residents are mostly young and well-educated and the economy revolves around tourism. Or it may be a wide-open area on the plains where the people come primarily from Slavic countries, the social life revolves around their church, and the economy depends on wheat farming. Of course, such units are in a constant state of flux, changing with times, conditions, and particular issues. But for the land manager concerned about the effects of a specific resource development, the unit of land and people provides a much-needed source of information and issues, which he can then incorporate into his decisionmaking process.

IDENTIFYING THE HRU

In order to use the Human Resource Unit as a planning and management tool, the land manager must first determine where its boundaries lie. As previously noted, these boundaries do not fall along artificial, politically created lines. Instead, an HRU is a living, natural area, much like any ecological unit, except that this unit is bound together by people's relations to the land and to each other. In essence, the HRU is a survival mechanism—an area that people perceive as being integrally tied to their survival.

Because of the HRU's relationship to the land, and because people tend to settle within geographic boundaries, the HRU boundaries generally follow geographical features (such as a mountain range). As an example, if a community is being significantly affected by a mine, the boundaries of the HRU may run along the sides of a highway leading from the town to the mine site, or they may be drawn at the edge of a valley that includes both the community and the mine. The boundaries of the HRU include the entire area that primarily depends on the mine for its economic survival. An example of crossing political boundaries would be the case of a community in County A dependent on a mine in adjoining County B. In this situation, the community and the area surrounding the mine will be included in the same HRU even though the two are in different counties.

The boundaries of a Human Resource Unit are determined from observation and understanding of the area. The boundaries are identified, in fact, very much like the land manager might identify the boundaries of an ecological unit. To aid in this task, criteria have been developed to help describe or characterize an HRU. The characterization includes the cultural and economic aspects of the area. (Table 3 lists the key social variables used to describe the cultural and economic aspects of the HRU.)

Accurately describing these variables does require a certain amount of skill, for, to be of use, the description must detail and record the reality of the environment. Thus, the land manager may require the skills of a sociologist to help him fix the boundaries of the HRU.

• **The cultural description.** In order to determine what groups of people are linked together in the HRU, the manager must identify and summarize the characteristics of the people in a given geographic area to see if there are common traits. The information can be collected by observation, through existing publications and research, by informal contact with people, and by simply being a resident of the area. The cultural description should include: what kinds of people first settled the area; what kinds of people live there now; and why they came to the area. Work routines, land ownership patterns, recreational preferences, social networks, and the history and culture of the area are other important descriptors. The cultural description should also look at the people's perceptions of their community, themselves, newcomers, and change. From these descriptors, the existing publics can be identified. An existing public is defined as a specific part of a population that can be grouped together because of some common interest or purpose. Examples are networks of ranchers, loggers, small businessmen, or retirees.

• **The economic description.** The economic description concentrates on economic management systems and financial aspects of the unit. This characterization of the community would look at the average annual rate of population change in the HRU, mix of employment by industry, wage structure description, and size of reserve labor supply.

By writing down these descriptions, the forest manager will gain a useful insight into the area. First, the descriptions help define the unit boundaries, because they will clearly show which lands and communities are tied together by physical dimensions, history, culture, and economics. These descriptions will begin to reveal a great deal about how the people within the unit relate to the land—for example, whether they depend on it for agriculture or recreation, whether they see open space as an essential part of their lifestyle, or whether they would welcome growth to boost a dwindling local economy.

Of course, defining the boundaries of the HRU is only the first step in gaining these insights. To further understand the people in the HRU, the land managers must stay in touch with its communication networks.

Communication networks are the routine ways people share information. If the resource manager can stay in touch with these networks, he can maintain his involvement with the public and be better prepared to anticipate and handle issues that affect management of forest lands.

Communication networks can be broken into two types: formal and informal. Formal networks represent the organized, visible interests of the community. Types of formal networks include: economic networks, such as a labor union; ideological networks, such as a preservationist club; and formal political networks, such as county commissioners.

Informal networks also represent various types of interests; however, they are not as visible. Types of informal networks include: survival networks, such as people sharing a common occupation; cultural networks, such as extended families; and caretaking networks—those people in the community who are relied upon for advice or for help in time of need.

In addition to these networks, which are within the HRU, the land manager must be aware of external networks that will influence management decisions. Again, these networks can be formal or informal; the difference is that they might be regional, national, or even international in scope. An example of a formal network on a national basis is the Sierra Club. An informal network could be people involved in a

Table 3. — *Key variables used to characterize a Human Resource Unit*

Type of variable	Variable name
Cultural descriptors	Existing/future publics
	Settlement patterns
	Work routines
	Communication networks
	Supporting services
	Recreational activities
	Geographic boundaries
Economic indicators	Population change
	Employment mix
	Wage structure
	Local labor supply
	Input-output ratio
	Capacity of government services

certain type of recreation—for example, backpackers and cross-country skiers who are from an urban area outside the HRU, but who use the forest.

Once these networks are identified, the resource manager will have a better grasp of the kinds of publics he must deal with, and the people he can go to for opinions or direction in resolving issues. One way to keep in touch with these networks is to develop a "key contact list." Such a list not only includes politicians and sportsmen's clubs, but also the key people in the informal networks.

EXPANDING THE BOUNDARIES

The HRU concept can be expanded from the local community that is tied to a forest to a wider area of people tied to a region. This broader area, known as the Social Resource Unit (SRU), can be used for regional planning. In both cases, however, it should be realized that the boundaries set up to characterize either the Human Resource Unit or the Social Resource Unit are fluid—the lines change with issues and management concerns. For example, at times, the interested publics may extend to a regional, national, even international level. Thus, the HRU or SRU must be constantly monitored for alterations in the boundaries. The precise boundaries, however, are not so important as is the fact that this approach helps the land-management team become more sensitive to human concerns.

As noted at the beginning of this chapter, the HRU and corresponding SRU are tools that can be used by nonsociologists. A sociologist or economist, however, is valuable in initially helping the land manager set up a system for identifying the HRU. To do this, the sociologist should submerge himself in the culture while he is working with the land manager to develop the HRU. Then, the process and the results should be documented so that the procedure can be followed when the sociologist is no longer on the scene. In this manner, a new manager assigned to the area can be brought up to date on tne characteristics and key concerns of his publics much more quickly than if he were left to his own devices. In other words, the HRU can be taught to a nonsociologist, as well as implemented by this nonsociologist, and the knowledge can then be readily transferred to new members of the team.

HOW THE HRU IS USED

Once identified, the HRU becomes usefu both for planning and day-to-day management In general, it can serve three broad functions:

• Knowing the publics that use the forest which results in better management.

• Providing a way of implementing the firs step in forest planning: issue identification and evaluation.

• Providing a data base that can be used fo social impact assessments in completing Environmental Assessments and Environmental Impac Statements.

The HRU can serve these functions because i will help determine how the people of an are relate to and rely on the land; how new developments may affect these people; and finally, hov the community will respond to planning an management decisions on NFS lands.

• **Public involvement.** Although Fores Service personnel have traditionally communicated informally with the publics using th forests, in recent years this informal give an take has evolved into more formal methods o communication. Because of this, the land manager in many cases has lost a "feel" for the community—a decided disadvantage when he is trying to identify issues during the planning process.

The HRU helps the forest manager regain firm grasp of the nature of the people the fores serves by helping him become more involved i the area's communication networks.

Through these networks, the land manage can:

• Identify emerging and existing public issues

• Inform people of resource management activities.

• Become informed about each public's interests regarding resource management.

• Dispel rumors about the agency and its activities, and educate people about agency concerns.

• Involve people informally before forma public involvement occurs.

• Understand how each public is affected b resource management plans.

• Insure that all involved publics are represented in the decisionmaking process.

In other words, because of his knowledge of the HRU, the forest manager will establish contacts with his public and gain a better understanding of what his role should be in managing the forests. He will also be less likely to focus only on internal management concerns. The HRU structures the manager's public involvement and provides a framework for quickly familiarizing the new manager with the characteristics and communication networks of the community he has moved into.

• **Issue identification.** Once communication networks are identified, the manager will learn what the public interests are. If he can manage in harmony with these interests, he can reduce the number and seriousness of issues. For example, if people like to fish, he provides fishing opportunities. If people like to hunt deer, he increases deer habitat. In other words, the resource manager uses the communication networks to find out what the people's interests are and, if possible, responds to them before they become issues.

Of course, rarely is managing public lands this simple. In many cases, the land manager *will* be faced with issues. But if he can address these issues before they become disruptive, he will be a more effective manager and provide better public service.

Knowledge of the HRU's characteristics and its communication networks will also insure that the ID team considers issues from all the existing publics, instead of just one vocal group. And, of course, the HRU provides a framework in which the manager can monitor an area and stay on top of emerging issues.

• **Social impact assessment.** The HRU can be used as the first step in a social impact assessment. A social impact assessment (SIA) is a systematic procedure for determining and predicting the cultural, institutional, and political conditions of a specific geographic area, and the way this area will be affected by specified changes. An SIA is often used when a mining development enters an area.

As set up by the social scientists who developed the HRU, 10 steps are necessary for completing a social impact assessment (fig. 5). For administrative reasons, it may be necessary to take the steps rapidly or to eliminate some steps altogether. But the more thorough the SIA, the better the results.

The 10 steps are grouped into three phases: (1) past/current situation; (2) future situation; and (3) management direction. Four steps are involved in analyzing the current situation; they provide baseline information about the HRU. With this "social" baseline established, the three steps used to characterize the future situation will help predict social changes resulting from proposed resource developments.

Finally, the three steps in establishing management direction will translate the results of the first two SIA phases into a basis for Forest Service action. The action proposed in this third phase of the social impact assessment should provide a practical alternative for allocating forest resources in ways that minimize the negative impacts of resource developments. During this phase, the manager should be able to plan ways to harmonize the natural environment with the proposed mineral, recreational, and/or other resource development activity.

The 10 steps in the SIA process involve:

1. Characterize the Human Resource Unit using cultural descriptors.

This step was discussed earlier in this chapter.

2. Characterize the Human Resource Unit using economic indicators.

This step was discussed earlier in this chapter.

3. Describe the relationship of the current situation to forest resources.

The purpose of this step is to identify the way residents and nonresidents of the HRU use forest resources. The relationship between people and the resources must be understood before the manager can begin to determine how the development force might interrupt that relationship.

Tasks in this step involve:

• Completing an inventory of each resource program output on the forest.

• Identifying uses of each resource program by resident and nonresident publics.

• Identifying demands on each resource program by resident and nonresident publics.

4. Describe the nature of the resource development force.

The principal characteristics of a resource development force are that it is sizable, will cause profound change, and will directly or indirectly impact management of the forest or the social

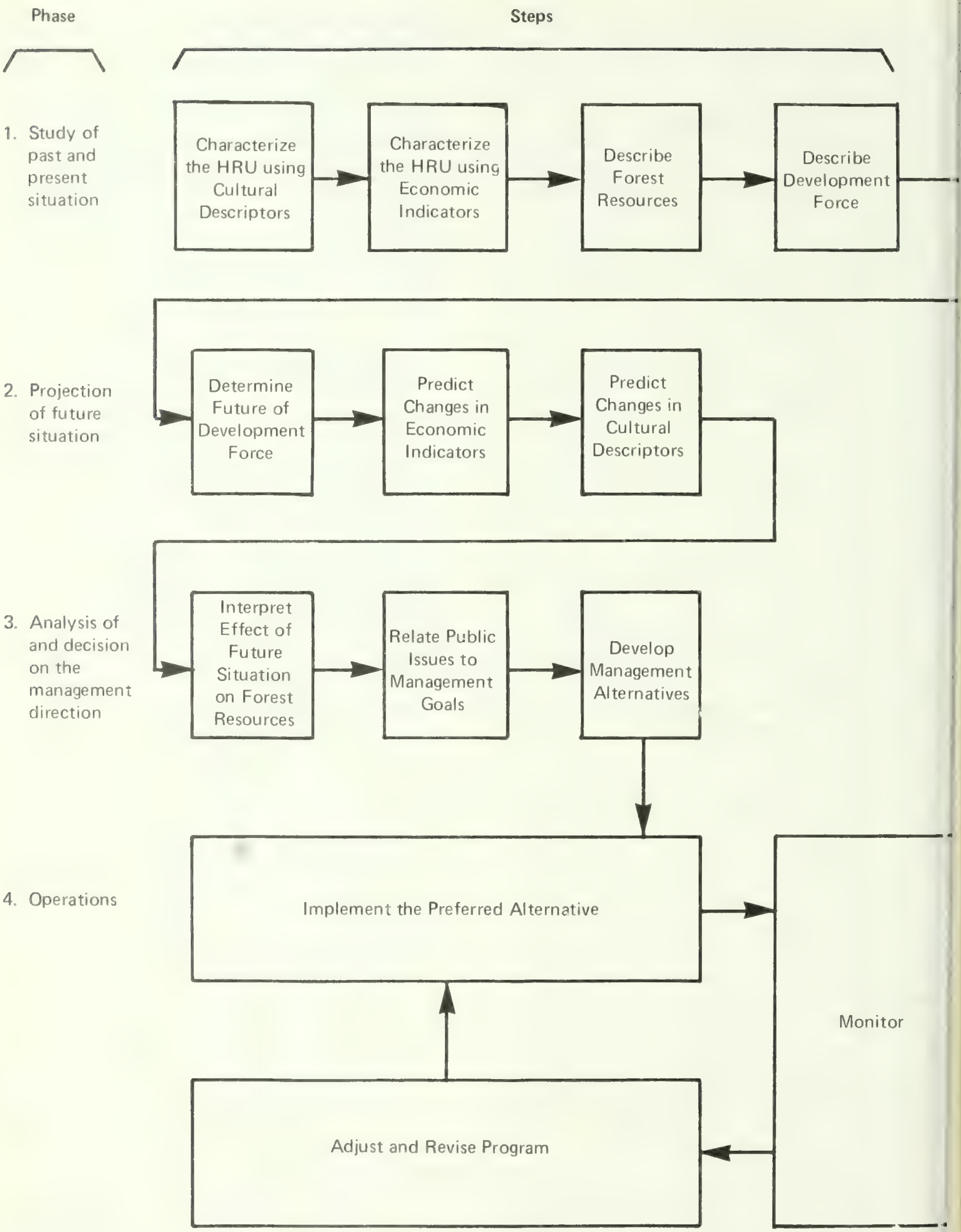


Figure 5. Steps in a social impact assessment (as related to the Human Resource Unit).

structure of the community. This step will help the manager determine the level of Forest Service involvement and when a management position must be taken.

Tasks include:

- Describing the location, type, size, and demand for the resource.
- Describing the technology and manpower employed in the resource development.
- Describing the practices and policies of the resource development.
- Describing the current phase of resource development.

5. **Determine the future of the resource development force.**

In moving from one phase to the next, a resource development activity, such as mining, must pass through very standard operations—for example, applying for permits, obtaining water rights, hiring miners. These procedures usually go unnoticed by resource managers until a crisis occurs. To prevent crises or minimize social disruption, it is important to understand that these activities ultimately will have an effect on an HRU. The impacts of concern to the resource manager are the direct effects of the industrial use of the forest and the indirect effects of a new population living near the forest. Thus, this step involves digging into the details of proposed or actual resource development plans and preparing for the next wave of change.

Tasks include:

- Estimating the timing of the future resource development phases.
- Charting the requirements for completing each resource development phase for 5-, 10-, and 20-year periods.

6. **Predict changes in the economic indicators.**

In this step, economic indicators are used as forecasting tools to signal rapidly changing situations.

The economic indicators used in step 2 to describe the present economy should be monitored for change. When analysis shows that these economic indicators are expected to move outside the normal range, the manager should begin to look for changes in the cultural descriptors.

Tasks in this step include:

- Predicting the rate of population change in the HRU.
- Describing changes in the mix of employment.
- Describing shifts in the average wage pattern in the major industries.
- Estimating the labor supply.

7. **Predict changes in cultural descriptors.**

The economic indicators only warn the resource manager that the economic conditions in an HRU will change with the resource development force. Changing economic conditions, in turn, set in motion a series of changes in the cultural conditions of an HRU. Therefore, the resource manager must reexamine the cultural descriptors characterized in step 1 to determine if the resource development force is creating positive or negative effects on the community.

Tasks include:

- Assessing the implications of change in the economic indicators for the cultural descriptors.
- Characterizing the HRU using the cultural descriptors in 5-, 10-, and 20-year periods.

8. **Interpret effect of future situation on forest resources.**

The results of steps 6 and 7 provide the manager with a basis for projecting future demands on the forest. This is essential to the resource manager who wants to stay in control of, rather than be controlled by, the rapid changes resulting from resource development.

Tasks include:

- Assessing the changing demands in each forest resource program for 5-, 10-, and 20-year periods.
- Predicting future issues for each of the existing publics associated with the resource development force.

9. **Relate public issues to management goals.**

This step provides the manager with the crucial link between study and action in a social impact assessment. Up to this step, the essential tasks led to the development and refinement of his knowledge of the HRU and the change occurring in it. Now, he translates the results of steps 1 through 8 into a form that means something from a Forest Service management perspective.

Tasks involve:

- Establishing criteria that will be used in screening out public issues that relate to management goals.
- Screening out public issues that satisfy the criteria.
- Reviewing Forest Service management goals for the HRU in light of the public issues

screened out for special attention.

• Listing public issues that are harmonious with current Forest Service management goals for the HRU.

• Listing public issues that are ignored by or are in conflict with management goals for the HRU.

• Conferring with informal and formal leaders of existing publics in the HRU to obtain their input to the final selection of public issues.

• Distinguishing public issues requiring immediate Forest Service management attention from those that should be addressed in subsequent years.

10. Develop alternatives for management action.

This step is concerned with the establishment of several real alternatives to address how public issues will be integrated into management directions.

Tasks include:

• Identifying alternatives for action on public issues.

• Identifying favorable effects and unfavorable effects related to each alternative.

• Developing a tradeoff schedule for each alternative.

• Identifying costs for implementing each alternative.

• Identifying local agencies, citizens, or Government agencies that have primary and secondary responsibility for carrying out the alternatives.

• Conducting a formal public review of alternatives.

• Selecting and implementing a social impact management plan.

By using this approach, the social impact assessment will achieve the following goals:

• It will assure public involvement.

• It will enhance understanding of tradeoffs for each public.

• It will minimize surprises.

• It will distinguish local, regional, national, and international interests.

For more information on the Human Resource Unit concept and how it is used in planning and management decisions, refer to a report titled "An Approach to Social Resource Management," by James A. Kent, Richard J. Greiwe and James E. Freeman, Foundation for Urban and Neighborhood Development, Inc, and Joh J. Ryan, The John Ryan Co., for USDA Fore Service, Surface Environment and Mining Pr gram. January 1979.

ANOTHER APPROACH TO AN SIA

A slightly different approach to social impa assessments has been developed by the Denv Research Institute (DRI), Denver, Colo. It briefly summarized here to show the similariti and variations between it and the HRU approa to a social impact assessment.

As used by DRI, the social impact assessme follows these steps:

1. Determine the characteristics of the co munity and development project.

Community characteristics include size, pre ous level of development, location, quality public and private facilities, and suppo systems. Characteristics of the developme project can include ownership, capital inve ment, labor needs, duration, and rate of develo ment. These determinants indicate vulnerability but do not forecast change.

2. Set up procedural requirements to foll in assessing change.

This should include:

• Identifying different types of changes, o portunities, and problems expected.

• Developing estimates or indicators of ma nitude or severity of the change.

• Developing a method for forecasting a monitoring/responding to expected changes.

• Assessing state-of-the-art for classifyi these changes and identifying which impacts w occur for specified developments in specifi communities.

Because there are few formalized models f making these assessments, a heavy reliance forecasting by analogy will probably be nec sary.

3. Develop anticipatory techniques.

This step includes:

• Developing a parties-at-interest checklist.

Here, the sociologist would identify t actors and stake-holders in the area bei studied. These parties consist of: parties intern to the affected industry, such as owners, e ployees, stockholders; suppliers and custom

of an affected industry; competitors of an affected industry; government; and affected by-standers, such as residents, property owners, and resource users. Developing this list is useful for highlighting different levels of government and society, political relationships, and unique situations.

• Developing an impacts wheel.

DRI's impacts wheel is an application of the future wheel developed by Joel Barker, Jerry Glen, and Billy Rojas at the University of Massachusetts, Amherst[4]. In this procedure, a generalized statement of the impact from whatever development under study is made and placed in a centered circle. From that statement, positive and negative impacts branch out in circles. These circles can go to second and third order impacts. For example, a generalized statement of impact might read: "Reduced quantity and quality of public service resulting from growth in population." A first order spinoff might be: "Reduce schools' quality and resources." A third order impact might be: "Higher teacher turnover." (See figure 6.)

Using this tool helps the sociologist focus on the relationships and consequences that may result because of an expected impact. The tool could be used in a public involvement situation or with other members of the Forest Service staff in order to discover problem areas or concerns.

MODEL OF CULTURAL ECOLOGY

The model of cultural ecology is a conceptual approach that has been used successfully by anthropologists to analyze human groups, and has applicability in social impact assessments as well. This model provides a rationale for evaluating various checklists (such as the cultural and economic descriptors of the HRU), and understanding relationships between various aspects of the organization of human groups. It can help determine, for example, whether economic variables should be considered first, or whether political or ideological variables take precedence. It also provides a theoretical framework for relating the variables.

The following provides a general outline of this concept; see figure 7 for a diagram of the model:

1. **The basic premise of the cultural ecology model is that human groups are best understood as adaptive units.** That is, their primary purpose is to provide a vehicle for adaptation to the environment. The two important aspects of the environment to which groups must adapt are the natural (physical) environment and other human groups.

2. **The human group—for example, a community—is analyzed as an adaptive unit in terms of four major categories:**

• The subsistence base or the economics of the group. This includes factors such as employment base, level and distribution of income, characteristics of production, and ownership of resources.

• The social structure. This includes such factors as type of kinship organization, social stratification, demographic structure, voluntary organizations, and organizations that promote social well being.

• Political organizations. Governmental entities and informal opinion leaders are part of this category.

• Ideology. This includes the group's values, norms, expectations, beliefs, and aspirations.

3. **Of the above four categories, the subsistence base is assumed to have priority, because it is the first order of adaptation to the environment that a human group must make in order to survive.**

4. **Two implications of this model for predicting people-related impacts are:**

• The analysis begins with an examination of environmental factors that impinge on a group.

• The analysis of the group itself begins with an analysis of the subsistence base, or economic variables. It is predicted that as the subsistence base changes, the social, political, and ideological structures will also change. In other words, this model is based on the assumption that social, political, and ideological structures are more affected by changes in subsistence than the reverse (although there are some exceptions to

[4] Joel Barker, Jerry Glen, and Billy Rojas developed the future wheel while doing postgraduate work at the University of Massachusetts, Amherst, in the late 1970's. No publication of their work is known to exist.

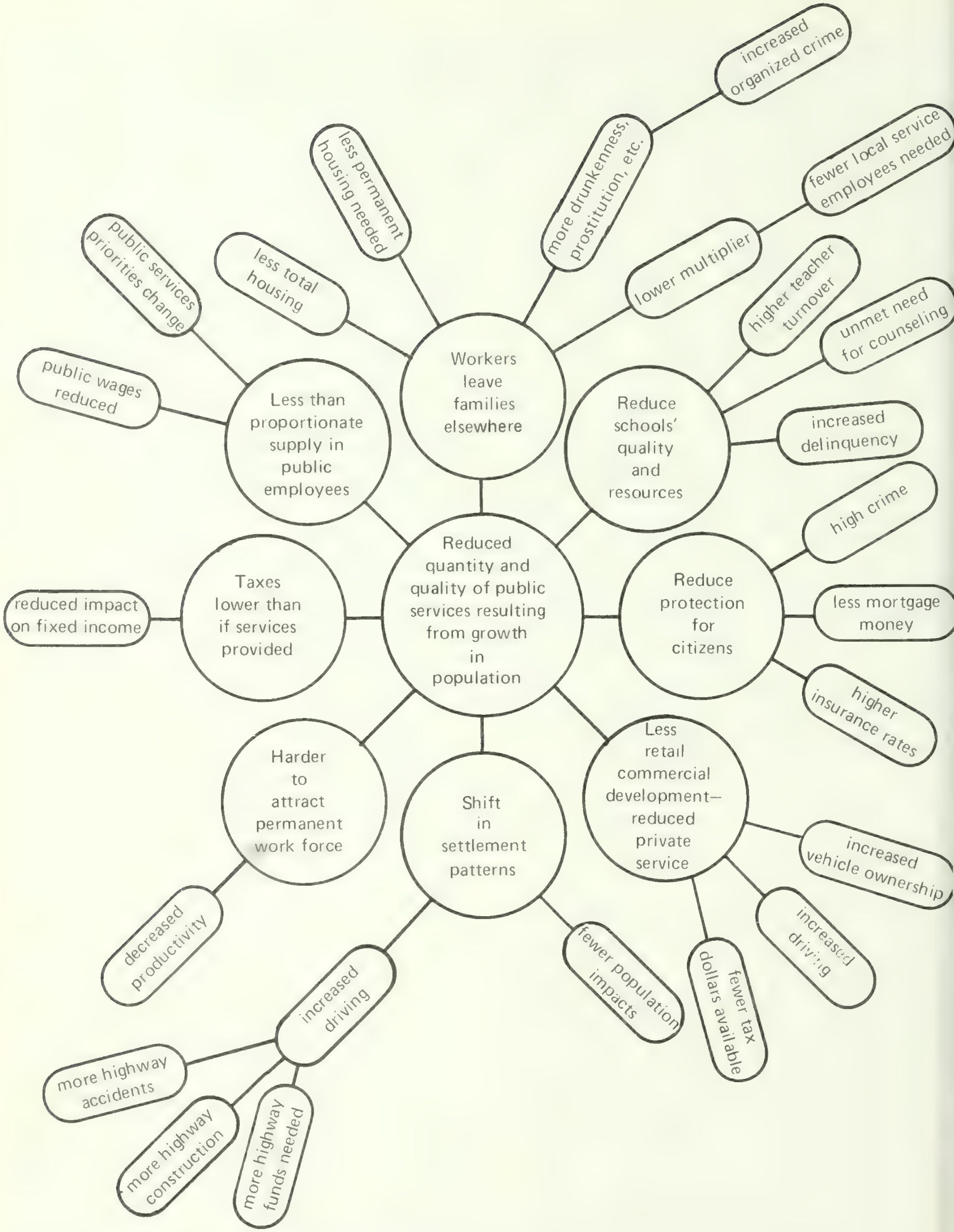


Figure 6. Impacts wheel. (Denver Research Institute)

THE ENVIRONMENT

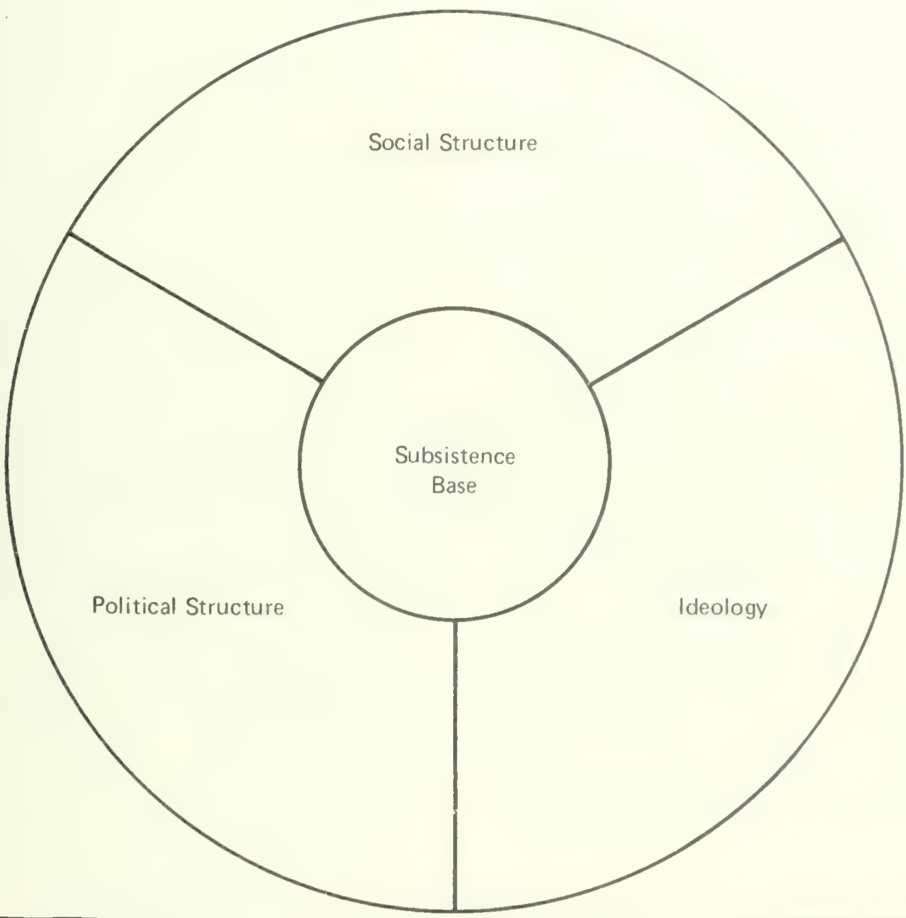
1) Natural Environment of Affected Region

Amount of water
Distribution of natural resources, etc.

2) Extra-Local Human Groups[1]

Interest groups
Impacting industry
State/national Government, etc.

THE HUMAN GROUP



[1] Extra-local groups are defined as groups that set policies or have perspectives or significant behaviors outside the impacted area [th]at help set the parameters, tone, and pace of change.

Figure 7. Model of cultural ecology.

this assumption). An example of how change in subsistence might affect the overall characteristics of the group is provided in table 4.

Thus, the model of cultural ecology directs that a social impact assessment begin with an analysis of the subsistence base. From this ana ysis, the sociologist can begin to predict wh types of social structures, ideological arrang ments, and political organizations will flow ou of the subsistence base described.

Table 4.– *Illustration of the effects of a change in subsistence on social structure, political organization, and ideology*

Subsistence	Social Structure	Political Organization	Ideology
		TIME 1	
1. rural agricultural economy	1. demography: small population size	1. rural interests influence decision-making and hold power e.g., county commissioners	1. value of individualis
2. family as the unit of production and ownership	2. family is the major household unit		2. personalism
	3. little elaboration of organization to promote social well-being (family performs these functions) health, mental well-being, social well-being, recreation, safety, etc.		
		TIME 2	
1. resource development occurs: coal, oil, gas, uranium	1. demography: increased population size	1. extra-local groups become increasingly important	1. attitude of willingn to rely on institutio rather than self or kin
2. resource firm as unit of production and ownership	2. household unit family, single individuals	2. industry and other professional personnel assume local political roles	2. impersonality develops
	3. development of public organizations (institutions) for health, mental well-being, social well-being, recreation, safety, etc.		

Chapter 4
THE ROLE OF THE ECONOMIST

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In recent years, the Forest Service has be- ome increasingly aware of the present and iture values of minerals contained within NFS oundaries. As a result, more emphasis is now aced on identifying mineral deposits, compar- g their value to other resource values, and esti- ating the potential and timing of their develop- ent.

In this context, the role of the economist is so gaining more prominence. Not only can he ring expertise to the job of calculating the over- l value of minerals on forest lands, but he can so work with minerals specialists to evaluate roposed mineral developments, both from a rict dollar estimate of costs and revenues and om a more judgmental benefit/cost study. In gard to a specific mineral development, the conomist might be asked to apply his skills in etermining the costs and revenues of the min- g development for the Forest Service, or the osts of various reclamation plans that other embers of the interdisciplinary team recom- end. He may also be asked to participate in viewing a mining operator's economic impact ssessment, if this study is required.

But because there are numerous approaches these types of economic studies, both the conomist and the land manager must be aware f the philosophical base of the economist. erhaps more than any other science, economic nalyses and predictions are inseparably tied to he conviction of the economist that he either an—or cannot—step into the realm of value nalysis and behavior predictions. In fact, under- ying many economic tools are basic value judg- ents of how the world is—and how it ought to e. Depending on their decision on what tools hey will use and what they will measure, several economists can interpret data quite differently. Thus, the economist must explain—and the land manager must demand to know—what value system and judgments underlie the economic analyses. And, of course, the philosophical bias of the land manager will dictate what functions he may ask the economist to perform for the interdisciplinary team.

Therefore, the land manager and economist must work together to establish goals and methods of analysis. If there is a staff economist assigned to the forest level, he must become grounded in the types of information his manager needs. If the economist is on loan from a Regional Office, he will need the same type of initiation. If the forest manager decides to let a contract for an outside economist to do a specific job, he should identify in the contract the types of skills and methodologies he will need. And, if a specific mining development is under study, the land manager and ID team may work with the mining operator's economist to help him understand what type of economic information will be necessary to make a decision on the development and reclamation of that site. Similarly, the economist must assist the manager in understanding the types of economic information that can be made available, and their implications for decisionmaking.

This chapter focuses on five areas in which the economist can provide expertise: cost and revenue analyses, value analyses, decision rules, behavior predictions, and economic impact assessments. A discussion of how the economist's skills can be put to use in inventorying minerals values on forest and national levels is also included.

COST AND REVENUE ANALYSES

Cost and revenue analyses are the most fundamental jobs an economist is trained to per-

form. In these analyses, the economist tries to pin down technical facts. For example, he would look at actual dollars and do a budget analysis.

Assessing supply and demand is part of this function. As part of the supply analysis, the economist can judge what the project or commodity under study will cost, what price/quantity relationships exist, when the supply will be available, and who will bear the costs.

Demand analysis will include: how much people will pay for the commodity; the price/quantity relationship; who will buy; how much and when they will buy. From this analysis, the economist can estimate relative and total costs and revenues of a development.

In regard to minerals developments, the economist should be aware that violent price fluctuations of mineral commodities are always possible, caused by such factors as international monetary exchange rates, foreign revolutions closing key mines, environmental pressures that lead to more stringent reclamation standards, and overall business cycles. Only for the short run can supply and demand be considered stable. On the demand side, this is generally true because industries using minerals as raw materials may have fixed their needs for several years into the future and will not quickly change them. On the supply side, the lead time required to discover, delineate, and develop new production facilities prevents increases in supply in the short run.

VALUE ANALYSES

Value analyses go beyond the technical facts to estimate the worth or social value of the commodity or development. The same methodologies applicable to cost and revenue analysis can be used, but in a value analysis, the economist addresses social values and social welfare questions. For example, he might set a dollar value on nonmarket goods, such as wilderness areas or on the use of the forest for recreation. He might use the tools of welfare economics to help clarify the comparison of health risks to economic gains. Value analysis looks at what tradeoffs must be made if a development takes place. From tradeoff analysis, the economist can determine relative cost/benefits. This type of analysis can be highly judgmental, depending on how it addresses social welfare questions. Th it is important for the land manager and ecor mist, as part of the interdisciplinary team, work together to set up planning objectives a criteria for both what will be measured and h it will be measured.

DECISION CRITERIA

This area of expertise relates directly to st 2 of the planning process. And, because e nomics is often called a decision science, ecor mists will have the specialized rules of behav and analytical tools necessary for helping land manager establish decision criteria.

Economics in general is oriented around c cepts such as efficiency, finding the optir solution to a set of decision criteria, maximiz benefits, or minimizing costs. Some types of cision behavior will lead towards these resu even though the decision to be made is too cc plex to be based on any single analysis or inc such as a benefit/cost ratio. One of these ty of behavior is structuring a detailed trade analysis. Another, and perhaps a fundamer behavioral principle, is to make decisions at margin. That is, to examine the change in out caused by small changes in activities—rather th comparing total outputs and costs—and ma decisions accordingly.

Similarly, the economist's specialized analy cal tools, such as benefit/cost analysis, mathen tical programming, and operations research te niques, will assist in both setting up the decis criteria, and then analyzing how well the d ferent alternatives meet the criteria.

BEHAVIOR PREDICTIONS

The economist may be able to predict haviors both for the economy as a whole—cal macro-economics—and for a single firm or sin industry—called micro-economics. The ecor mist can take supply and demand informati and, using some judgment, determine answers questions such as: When will industry show interest in developing a mineralized site? W will be involved? Where will it take place? W and how? In other words, he will analyze sup and demand and predict at what price it is e

nomically viable to develop certain deposits. He can then tie this into the location of the deposit most likely to be mined, assess what technology might be used, and make a preliminary estimation of the impacts that will result—changes in income, tax base, etc. And, he can predict what causal mechanisms will result in a change in direction toward developing the deposit.

Of course, many factors beyond the control of either the Forest Service or the mining operator can change supply and demand curves over the long run. Thus, these predictions must constantly be evaluated for their validity.

ECONOMIC IMPACT ASSESSMENT

If a resource change will occur—for instance, a mine will be developed—the land manager will need to know how to predict supply and demand changes in the forest as a result of new wage structures, added population, and/or new recreational preferences. The economist can aid in this evaluation by doing an economic impact assessment, which can be tied into the larger social impact assessment discussed in chapter 3.

An economic impact assessment is comprised of three parts: budget and fiscal impacts, economic activity impacts, and economic and social structural changes.

• **Budget and fiscal impacts**. These impacts are assessed from a strict dollar aspect and can look at the forest's district office, supervisor's office, local Governments, and organizations and firms.

• **Economic activity impacts**. The economist can predict the ripple effects the resource development would have on the economy as a whole as a result of its development.

• **Economic and social structural changes**. Again, this analysis focuses on what will happen as a result of development that will affect how the people in the community will earn their living.

The economist can predict where prices, industries, employment patterns, and incomes will change. He can identify changes in income distributions. In terms of the model of cultural ecology presented in chapter 3, he can identify changes in the subsistence base. These changes will lead to a different economic and social structure in the community, different economic and social roles for individuals within or coming to the community, and different community power bases. Thus, the economist can work with the sociologist in predicting social changes.

This kind of analysis will help the ID team anticipate issues, and thus points out the important role the economist can play in issue identification. In other words, his economic analyses can provide the manager with information on changes in: tax base, income levels, wage structures, price levels, employment rates, and changes in types of industries, levels of economic activities, or types of workers. All of these changes can cause issues to emerge.

PREDICTING MINERAL VALUES AND DEVELOPMENT POTENTIAL

On a forest, the tools of the economist can be used to place a value on the minerals within the forest's boundaries and to predict when these minerals might be developed, in what sequence, and at what price. This information will be valuable to managers who are now being directed by various regulations to decide how mineral deposits on public lands will fit into the overall land-management plan.

The value of a deposit is based in part upon the ore grade and the cost of production per ton. Other factors being equal, the higher the ore grade, the less costly per ton it will be to mine. Some organizations have attempted to evaluate mineral deposits using ore grades and other features of the deposit. For example, the Bureau of Mines has looked at some 20,000 mineral deposits around the country and has estimated how expensive, in a strict economic sense, it would be to mine these deposits. The resulting information is compiled into the Minerals Availability System (MAS). If similar information can be compiled on a forest level, the mineral deposits in a forest can be compared to those of the nation to estimate their comparable rank. Then, after comparable values are determined, the economist can estimate the demand to develop and use these deposits. From this, he can predict when the various deposits might be mined and what value that mineral deposit will have at the time of mining. Of course, such an analysis is subject to error because of the volatile price fluctuations mineral commodities can take,

and the fact that demand for a certain mineral may change over the long term.

An estimation of the effects of not mining in the sequence of least cost to most cost should also be made. For example, if social values dictate that a mine should not be developed, not only will the next least-expensive deposit of the same mineral be more expensive to develop, but also, society will come to the end of the supply more quickly. The benefit of skipping over this mine, then, must be looked at in terms of its present effect on the economics of developing the next mineral deposit, and the future impacts of not mining it.

Finally, from the information gathered up to this point, the economist and land manager can compare the value of developing mineral resources to the value of other resources and make tradeoff comparisons. This type of economic information helps the land manager, economist, and other members of the ID team budget and project outputs and targets for the 50-year planning period prescribed by the Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974.[5]

ECONOMIC SKILLS AND RPA

Under RPA, an assessment of the National Forest System's renewable resources must be made and used as the basic information for planning.

As amended in the National Forest Management Act (NFMA) of 1976, RPA directs that planning for resource allocations requires: (1) the best available resource data and information, including the views of citizens and special interest groups and all levels of government; and (2) the synthesis and evaluation of such data and information, utilizing professional and administrative judgments on how to best meet statutory goals and objectives and achieve the interest and expectations of the public. Specific to minerals is the mission to integrate the exploration and development of NFS mineral resources with the use and protection of other resource values. Obviously, this directive will involve economic skills, since RPA specifies a program of assessing the value of minerals on NFS lands and their value in relation to other resources.

The task force set up to implement RPA is the Resource Program and Assessment group (also RPA), based in Washington, D.C. This group is working to establish a common denominator on which to base comparisons of both market and nonmarket values for each of the resource program elements and supporting elements identified in the RPA and NFMA regulations.

The result of this analysis will provide national direction to the regions on output and budget targets covering a period from 1981 to 2030. In addition, the methodologies used by RPA can be followed by the regional and forest level planning staffs to do similar analyses as part of their planning and management programs.

The resource program elements to be studied are recreation, wilderness, wildlife and fish, range, timber, water, minerals, and human and community development. The supporting elements include protection, lands, soils, and facilities. Most of these elements are broken into subunits. As an example, subunits under timber are new timber sales, reforestation, timber stand improvement, and other timber sales. At the time of this writing, an economic analysis for each subunit resource is being completed, and this analysis is further broken down into each of the National Forest System's (NFS) regions and stations. The economic analysis also looks at several management alternatives. Market goods to which a price can be fixed are analyzed, as well as nonmarket goods, and both inputs and outputs are looked at. For example, in timber an input would be timber road building. An output would be board feet of sale.

The result of this analysis is to tie together all the resource elements with information on inputs and outputs for a 50-year period. These data will be studied to determine what direction the NFS will take in managing natural resources

---

[5]U.S. Laws, Statutes, etc. Public Law 93-378. [S. 2296], Aug. 17, 1974. Forest and Rangeland Renewable Resources Planning Act of 1974. An act to provide for the Forest Service, Department of Agriculture, to protect, develop, and enhance the productivity and other values of certain of the Nation's lands and resources, and for other purposes. In its United States statutes at large. 1974. Vol. 88, pt. 1, p. 476-480. U.S. Gov. Print. Off., Washington, D. C. 1976. [16 U.S.C. 1601.]

under its jurisdiction, taking into account not only economic criteria, but also environmental, social, and physical constraints. In essence, it is a type of national cost/benefit analysis for developing and managing NFS resources for several different management alternatives.

Preliminary results of this analysis show that the net present worth benefit of minerals on NFS land is almost as great as those figures calculated for timber production—and that, for several management alternatives, minerals in some regions have a greater dollar value than timber. (Net present worth benefit is present worth benefit less present worth cost. Figures are in dollars and have been assigned to many market and nonmarket NFS outputs. "Social" values are not figured into this particular study. See table 5.)

RPA has also developed tradeoff comparisons between resources for various management alternatives. (See figures 8-10.) This type of tradeoff analysis sets up a goal (for example, to produce X number of board feet/yr from X area), and then relates what effect this activity will have on other resource activities; what the costs might be; what technology might be used; and what type of management might be employed.

As the graphs show, using one management alternative instead of another reduces the tradeoffs involved when the management of one resource over another is being emphasized. The five management alternatives are:

1. Total development, including high market outputs and high nonmarket activities. Obviously, this alternative would be the most costly to manage.

2. Stewardship, which would mean very little or no development.

3. Moderate market outputs and moderate nonmarket activities.

4. High level of nonmarket activities—for example, an emphasis on wilderness preservation, and a low level of market outputs.

5. Current management program.

A similar type of tradeoff analysis can be done on the forest and regional levels. And, in addition to tradeoffs, the economist can assess what activities complement each other. For instance, building a road to get a mine in is complementary to later having a road to get timber out. The tradeoff is in wilderness value lost.

RPA's studies and recommendations will become operational in 1981. They will establish national policy targets for a timespan from 1981 to 2030. These targets, however, will be reevaluated and adjusted every 5 years. For the economist on the regional or forest level, such direction will provide guidelines and methodologies for his or her own future economic analyses.

Table 5.— *NFS resources, net present worth benefits*[1] *(in billions of dollars at a 4-percent discount rate)*[2]

	Management alternative number				
	1	2	3	4	5
Total NFS	116.2	90.3	95.6	93.6	97.5
Minerals element	46.4	25.9	26.3	26.0	26.5
Timber element	34.3	29.4	34.0	28.0	36.1

[1]Prepared by Resource Program and Assessment, USDA Forest Service, Washington, D.C. Values are in billions of dollars and, for minerals, represent receipts to the U.S. Treasury from such sources as royalties and NFS sales of gravel and sand. For timber, the figure represents both receipts to the U.S. Treasury and the market value of stumpage.

[2]Data base No. 13, Resource Program and Assessment, 1981-2025 time period.

Figures 8-10. The graphs on this and the following pages were developed by the Resource Program and Assessment group, USDA Forest Service. They illustrate that tradeoffs between managing for one resource over another can change dramatically when various management alternatives are used. In particular, when new technology is employed in minerals production, the tradeoff usually is less—a plus for the land manager concerned with balancing resource uses on National Forest System lands.

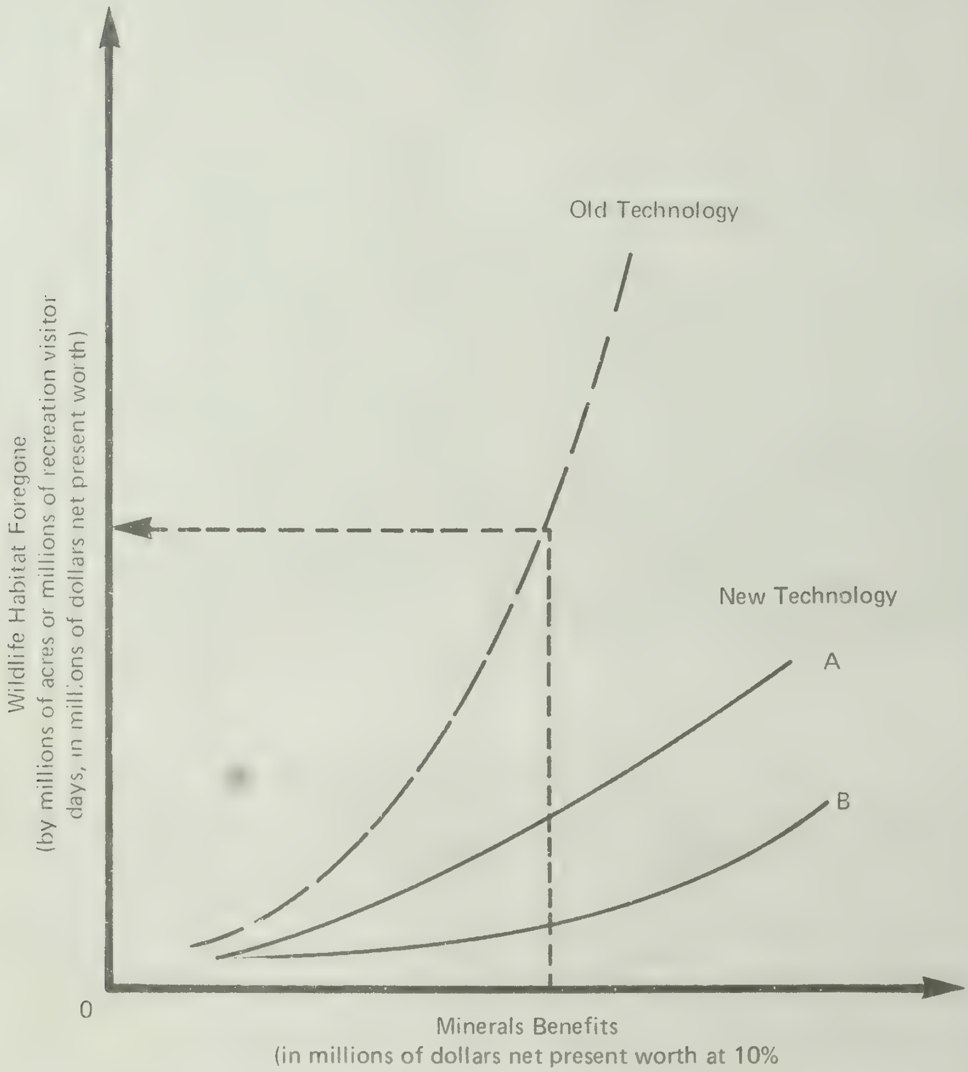

Figure 8. Illustration of tradeoff comparison between minerals and wildlife.
(Data base 11, Resource Program and Assessment)

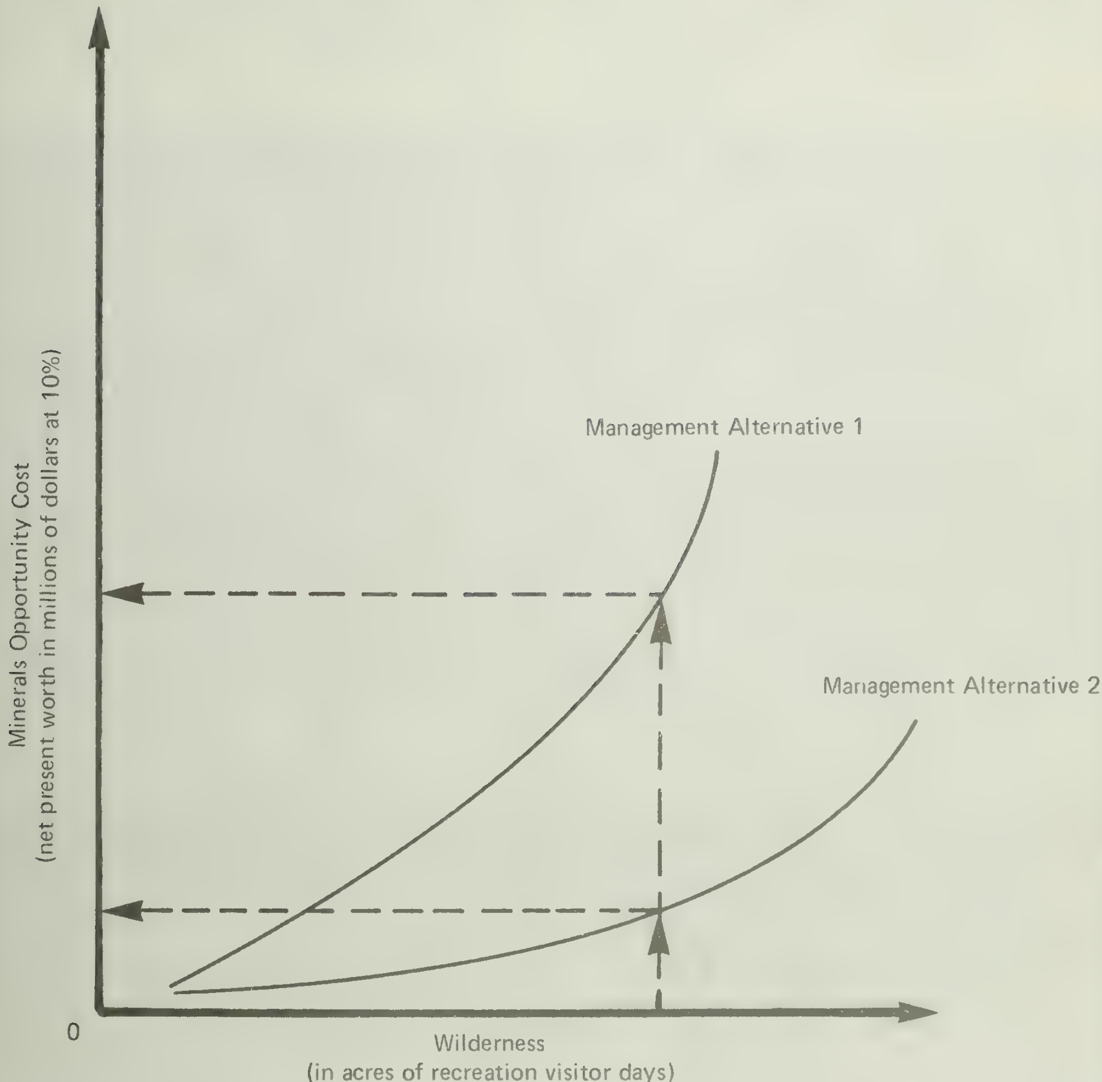

Figure 9. Illustration of tradeoff comparison between minerals and wilderness.
(Data base 11, Resource Program and Assessment)

SUMMARY

As the topics covered in this chapter illustrate, the Forest Service economist's role is tied to a number of variables. He may be asked to look at economic factors on a national level, or he may apply his skills to a site-specific development. The skills and methodologies he employs will be related to his philosophy and education, as well as to the direction given him by the land manager or ID team. How well the economist's skills are used in minerals-development decision will be largely dependent upon how well th economist can explain his tools to decisior makers and those responsible for the plannin and implementation of plans. But as the econc mist is able to demonstrate that better decision can be made because of his input, there is n doubt that he will be drawn more and mor heavily into the decisionmaking process involv ing minerals development on NFS lands.

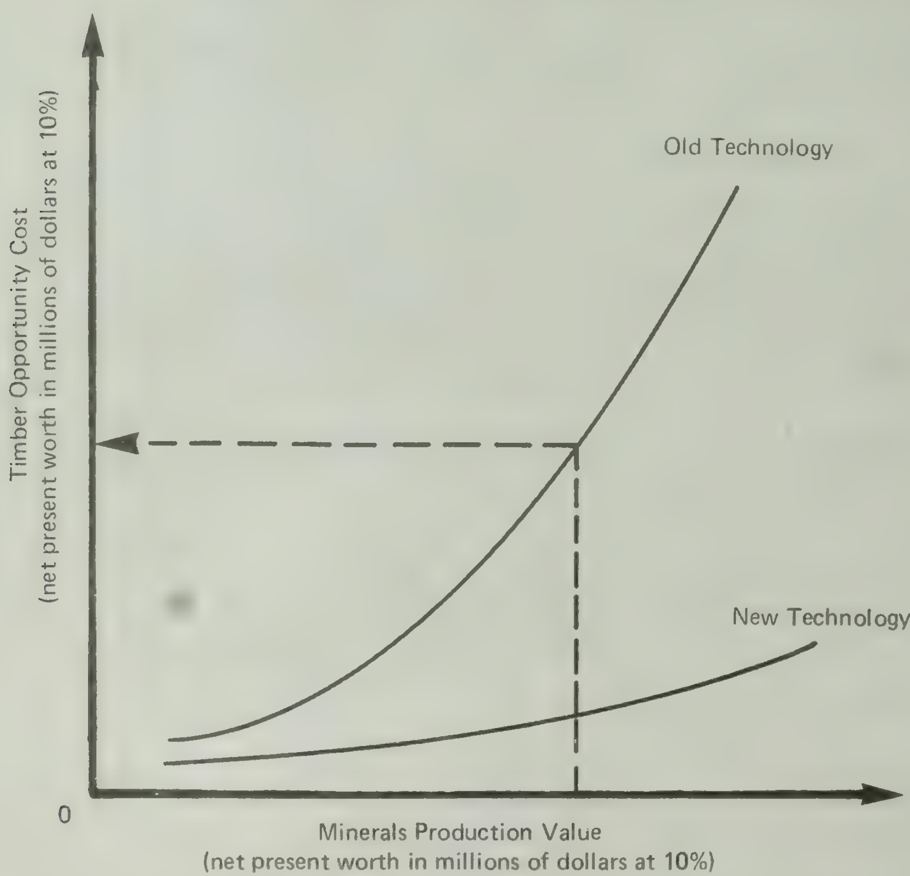

Figure 10. Illustration of minerals opportunity cost comparison to timber. (Data base 11, Resource Program and Assessment)

Chapter 5
THE ROLE OF THE SOCIOLOGIST

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Nowhere is the importance of public input into the planning and management of Forest Service lands more important than where minerals developments are involved. Such developments, unless quite small, can significantly alter the fabric of the community surrounding the forest, resulting in numerous issues and management concerns. Consider the following scenario:

> A small ranching community lying in a sparsely populated river basin has recently become the hub of an energy boom—the result of increased coal mining activities in the basin. Development has come at a rapid rate without planning, resulting in an uprooting of longtime residents, an increased cost of living, disruption of the wage scale, overcrowded schools and housing, and overloaded recreation facilities and service. The negative impacts have had their effects on local residents and newcomers alike.
>
> No localized recreation has been developed in the vicinity of the town to accommodate this large growth. The old recreational values such as rodeoing, hunting, and fishing that surround ranching life are not satisfactory to the "newcomer" recruited primarily from Eastern coalfields. This lack of local recreation has sent thousands of new miners to a national forest several hundred miles away. The Forest Service was unprepared for the impacts generated by their influx.
>
> The new users of the forest have no knowledge about the physical limitations of the land and their effect on its recreational potential, or about the pride longtime residents have taken in the forest. A four-wheel drive playground has been created which is wreaking havoc with Forest Service management by causing new erosion sources and a general deterioration of esthetic values in the forest.
>
> Local residents have become angered by the "invasion" of their forest, and their traditional partnership with the Forest Service in caring for this public land is showing signs of stress. Residents are beginning to feel they would like to keep the newcomers out.

Obviously, social and economic concerns—the concerns of people—are being expressed by the users of this forest. And, this is only one example of the impacts energy developments have on the forests—whether or not the mines are located within National Forest System boundaries.

In this context, the skills of the sociologist are valuable. By definition, a sociologist is trained to analyze the forms, institutions, and functions of human groups—and how these groups respond to change. Thus, he can help the land manager identify and integrate the public's concerns and demands into land-management decisions, and he can help the land manager understand the effect various land-management practices will have on the public. In other words, similar to staff specialists, such as the hydrologist or soils scientist, who collect and analyze technical information for the land manager, the sociologist can apply sociological methodologies to the analysis and prediction of human behavior, and translate the results into a form that will be useful to the land manager in his decisionmaking processes.

The sociologist can also play a role internally within the Forest Service. Again, because of his training, he may be called on to help other members of the forest staff become more attuned to the messages the public is sending, and, within the organization itself, to understand the

principles of human interactions and group dynamics.

Of course, the functions a sociologist performs depend on his training, and will also vary from forest to forest and between levels in the Forest Service. For example, on a local level, the land manager may see the sociologist's role as "diplomat"—a person who can communicate well with the local community. At other times, the land manager may need the sociologist's analytical skills, which might include formation of a model of a component of society or devising survey instruments.

Thus, as is the case with other members of the Forest Service team, the sociologist's role will be directed by management. He may have skills in crisis intervention or community organization, and he will use these skills at the request of the land manager. It is, however, also important to note that whereas other specialists, for example, the soils scientist, have a long tradition with the Forest Service, the sociologist is a relative newcomer. Because of this, his role in the organization is still developing, and the sociologist may have to educate management about the skills he can contribute to the team.

This chapter will highlight the various kinds of roles the sociologist can play on the forest level, especially as these activities relate to minerals developments and the effects these developments have on communities. For purposes of discussion, these roles have been broken down into six categories: describe, analyze, predict, translate, implement, and monitor.

DESCRIBE

The social, political, and cultural description of society is the baseline from which analysis, predictions, and management actions will develop. The sociologist, however, must place some boundaries on the amount and type of data he will gather to describe the society under study. These boundaries take the form of models and methodologies.

Sociological models are ways of looking at and analyzing human groups. (See chapter 3 for examples of these models.) Methodologies are specific techniques that can be employed by the sociologist. These can include ethnographie[illegible], survey research techniques, and demographi[illegible] studies—looking at statistics, such as death rate[illegible] and migration patterns.

The sociologist may develop his own model[illegible] and methodologies, or he may adopt those de[illegible]veloped by others in his field. But the purpose i[illegible] the same: to systematically describe the struc[illegible]tural parts of society and its systems. This de[illegible]scription will then provide the sociologist wit[illegible] the basic information he needs to proceed t[illegible] analysis.

ANALYZE

Once the baseline data are collected, the soc[illegible]ologist can fit the data into the model he ha[illegible] chosen and begin to make interpretations of th[illegible] data. For example, if population figures sho[illegible] that the community is rapidly expanding, and i[illegible] forest visitor-use figures show a correspondin[illegible] increase, he can interpret these figures to mea[illegible] that the increase in forest use is due mainly t[illegible] the increase in resident population near th[illegible] forest, and not to an influx of tourists.

The sociologist's skills in analysis are espe[illegible]cially valuable when change is occurring. Be[illegible]cause he has some understanding of the fabric o[illegible] the community through his studies and discus[illegible]sions with residents, he can relate this know[illegible]edge to other indicators of the community'[illegible] acceptance or rejection of the change. He ca[illegible] identify which segments in the society are mos[illegible] affected by the change, and which are leas[illegible] affected. And, as issues surface, the sociologis[illegible] can help determine the source of the issue[illegible] whether the issue is of local, regional, o[illegible] national concern, and whether the Fores[illegible] Service can resolve the issue. In other words[illegible] because of his skills in zeroing in on wha[illegible] members of the community say, think, an[illegible] value, the sociologist will often be the primar[illegible] identifier of public issues.

Another analytic role involves evaluation o[illegible] management alternatives. At the request of th[illegible] line officer, the sociologist might analyze thes[illegible] alternatives to determine the one that will bes[illegible] maximize social benefits, minimize social disrup[illegible]tion, and be politically feasible. Cost/benefi[illegible] studies are part of this analysis.

PREDICT

Analysis is closely tied into prediction. Based on what the sociologist interprets from data on the current situation, he may be able to go one step further and predict the future social consequences of certain actions and predict future issues. In the case of a minerals development, he may be able to predict the social consequences of the development—jobs affected, recreation patterns altered, and value systems impacted. He can often predict who will be the future "winners" and "losers" in a development, and why this is so.

The sociologist, through his analysis, can also pinpoint certain trigger points, or causal mechanisms, that will induce changes. By watching for these trigger points, he can help the ID team anticipate the shockwave of emerging issues. Of course, this is not to say that other Forest Service personnel will not take part in predicting issues. But the sociologist, because of his education, training, and experience, can usually become more quickly attuned to this type of activity.

A more formal approach to predicting the social consequences of change is taken in a social impact assessment. The Forest Service sociologist may find it necessary to prepare a social impact assessment for the forest, for example, as part of the forest plan. Or, he may be responsible for reviewing the social impact assessment prepared by a mining company as part of its Environmental Assessment or Environmental Impact Statement. A social impact assessment can be defined as: an analysis of externally induced changes affecting social and economic systems and the people and institutions making up those systems. (See chapter 3 for more information on social impact assessments.)

Of course, evaluation of change is difficult because change is qualitative; because the evaluation depends on people's perceptions at any given point in time; and because these perceptions will change, as will the events to which they are responding. In addition, it is difficult to collect reliable data to make such qualitative types of assessments. The sociologist, however, can help the land manager evaluate available data—an important aid for the manager's planning and management strategies.

TRANSLATE

One of the most important roles of the sociologist is to translate his descriptions, analyses, and predictions into a form that will be useful to the land manager. Similarly, at the direction of the land manager, he may be asked to translate Forest Service policy into the language of the community.

Another aspect of the translator role is to make sociological skills usable by the nonsociologist. In other words, the sociologist should be able to explain methodologies, models, and other sociological tools well enough so that the land manager and members of the ID team can participate in social analysis. This is especially crucial if the forest does not have a full-time sociologist assigned to it. In these cases, a sociologist from the regional level may be asked to help set up a public involvement process for the land manager, and when he leaves, the process should be operable by the staff on duty in the forest.

IMPLEMENT

At the discretion of the line officer, the sociologist may also be asked to use his skills in the area of implementation—translating management plans into actions. For example, he may be asked to go into the community, and, based on his analysis of its character, work with it to resolve an issue. He may be asked to implement human interaction programs, plans, and management strategies for dealing with the community. And he may be asked to apply his knowledge in crisis intervention.

The following list gives some examples of the sociologist's role in implementation:

- Establish communication networks between the Forest Service and its publics, and, in particular, strengthen informal communication networks.
- Separate long-term planning issues from short-term operational issues, help carry out the plans for resolving these issues, and keep the public informed of these activities.
- Develop and implement conflict strategies and methods of crisis intervention.
- Aid in the on-going *process* of planning by

applying skills of decisionmaking processes.

- Help the land manager become more attuned to the political groups in the community and the political aspects of resource decisions.

MONITOR

The processes of social description, analysis, prediction, and implementation are ongoing. Thus, the sociologist must constantly monitor the community for changes that may, in turn, require revisions in management practices and plans.

APPENDIX A

GLOSSARY

Baseline data: In reference to sociology and economics, baseline data are the social, political, economic, and cultural descriptions of a society from which analysis, predictions, and management actions will develop.

Communication network: A group of individuals who form a system for maintaining or activating their interests—including both formal and informal groups.

Cost/benefit analysis (also benefit/cost analysis): An analytical approach to solving problems of choice, which identifies for each objective that alternative yielding the greatest benefit for a given cost or that alternative producing the required level of benefits at the lowest cost. This same analytical process has also been referred to as cost effectiveness analysis when the benefits of the alternatives cannot be quantified in terms of dollars.

Decision criteria: Goals and objectives that will resolve the issues, management concerns, and program requirements identified by the planning team. These criteria also provide guidance for evaluation and selection of alternatives during the planning process.

Discounting: The practice of placing a lesser value (economic or other) on future events than on present events for the purpose of comparison. An item received today is seen to be worth more than an identical item received next year.

Discount rate: The interest rate used in plan formulation and evaluation for discounting future benefits and computing costs, or otherwise converting benefits and costs to a common time basis.

Economic impact assessment: An assessment of the economic impacts of change on a community; it consists of budget and fiscal impacts, economic activity impacts, and economic and social structural changes.

Environmental Assessment (EA) (Replaced the EAR): An analysis of all actions and their predictable short- and long-term environmental effects, which include physical, biological, economic, and social factors and their interactions. Also, a concise public document required by the regulations for implementing the procedural requirements of the National Environmental Policy Act of 1969 (NEPA).

Environmental Impact Statement (EIS): A document prepared by a Federal agency in which anticipated environmental effects of a planned course of action or development are evaluated, as prescribed by the National Environmental Policy Act of 1969 (NEPA).

Existing public: A specific part of a population that can be grouped together because of some common interest or purpose.

Feasibility study: As applied to mining, the feasibility study follows discovery of the mineral and is done by the mining company. Its purpose is to analyze the rate of monetary return that can be expected from the mine at a certain rate of production. Based on this study, the decision to develop the ore body may be made.

Forest plan: See land-management plan.

Goal: A concise statement of an organization's central strategy in addressing a problem expressed in terms of a desired state or process that operating programs are designed to achieve. A goal is usually expressed as a broad general statement, is generally not quantifiable, and is timeless in that it usually has no specific date by which it is to be completed. A goal is the principal statement by which objectives must be developed.

Human Resource Unit (HRU): A geographic area tied together by a common physical, social, and economic environment; the HRU is specific to the forest or district level. It can be used as a planning and implementation tool for forecasting and managing the social impacts resulting

from changes in resource use on the forest or district level.

Impact: The force of impression or operation of one thing on another.

Inputs: The basic resources of land, labor, and capital required in carrying out an activity.

Interdisciplinary team (ID team): As proposed by recent Forest Service regulations, the interdisciplinary team will be comprised of Forest Service personnel who collectively represent two or more areas of specialized technical knowledge about natural resources management applicable to the area being planned. The team will consider problems collectively, rather than separate concerns along disciplinary lines. This interaction will insure systematic, integrated consideration of physical, biological, social and economic, and other sciences.

Land-management plan: According to Forest Service regulations, each forest must have a forest plan, which outlines the most desired and alternative land uses for that site.

Management concern: An issue or problem requiring resolution, or condition constraining management practices, identified by the interdisciplinary team.

Marginal decisionmaking: Making a decision by comparing tradeoffs resulting from small changes in actions instead of comparing total or average outputs.

Mining plan: Submitted by the mining operator, the mining plan outlines the steps the mining company will take to mine and reclaim the site. The mining plan is submitted prior to start-up of mining operations.

Objective: A clear and specific statement of planned results to be achieved within a stated time period. The results indicated in the statement of objectives are those which are designed to achieve the desired state or process represented by the goal. An objective is measurable and implies precise time-phased steps to be taken and resources to be used which, together, represent the basis for defining and controlli the work to be done.

Opportunity cost: The value of the benefi foregone or given up due to the effect of choc ing another management alternative that eith impacts existing outputs or shifts resources aw from other activities so that they are no long produced and their benefits are lost.

Optimization analysis: Analysis to determi which alternative program will maximize minimize a set of decision criteria, given certa constraints.

Outputs: A broad term for describing any r sults, products, or services that a process or a tivity actually produces.

Public issue: A subject or question of wid spread public interest relating to management National Forest System lands and identifie through public participation.

Reclamation: Returning disturbed lands to a form and productivity that will be ecologically balanced and in conformity with a predete mined land-management plan.

Rehabilitation: See Reclamation.

Social impact assessment: An analysis of ex ternally induced changes affecting social an economic systems, and the people and instit tions making up those systems.

Social Resource Unit: Similar to the Human Re source Unit, except that it covers a wider are, and thus can be linked to regional planning.

Sociological models: Models for systematicall describing and analyzing human groups and the systems.

Subsistence base: Economic variables that infl ence a group; these variables include employ ment base, level and distribution of incom characteristics of production, and ownership c resources.

Supply/demand analysis: The relationship c

mounts of goods available for sale at various prices to the amounts of goods that will be bought at various prices.

Tradeoff analysis: An analysis of the combination of benefits and costs which are gained and lost in switching between alternative courses of action. Tradeoffs include only those portions of benefits and costs which are not common to all alternative courses of action under consideration.

APPENDIX B

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USDA Forest Service.
1979. User guide to sociology and economics. USDA For. Serv. Gen. Tech. Rep. INT-73, 53p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Summarizes and discusses the roles of the sociologist and economist when working with the social and economic concerns that arise from minerals developments on or near Forest Service lands. Topics include land-management planning, issue identification and resolution, sociologic and economic tools for land managers, and role statements for the economist and sociologist in the context of minerals developments.

KEYWORDS: Sociology, economics, mining, land-management planning process, public issues

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KEYWORDS: Sociology, economics, mining, land-management planning process, public issues

THE SEAM PROGRAM

The Surface Environment and Mining Program, known as SEAM, was established by the Forest Service to research, develop, and apply new technology to help maintain a quality environment while helping meet the Nation's mineral requirements. SEAM is a partnership of researchers, land managers, mining industries, universities, and political jurisdictions at all levels.

Although the SEAM Program was assigned to the Intermountain Station, some of its research projects were administered by the Rocky Mountain and Pacific Southwest Research Stations.

MINERAL USER GUIDES

Other User Guides for specialists involved in minerals activities are:

- User Guide to Vegetation, Gen. Tech. Rep., INT-64
- User Guide to Soils, Gen. Tech. Rep., INT-68
- User Guide to Engineering, Gen. Tech. Rep., INT-70
- User Guide to Hydrology, Gen. Tech. Rep., INT-74
- User Guide for Wildlife (planned)
- User Guide for Visual Management (to be published as part of the National Forest Landscape Management Series)

To obtain copies of these guides, write: Intermountain Forest and Range Experiment Station, USDA Forest Service, 507 25th St., Ogden, UT 84401.

USER GUIDE to HYDROLOGY

Mining and Reclamation in the West

U.S.D.A. FOREST SERVICE
GENERAL TECHNICAL REPORT INT-74
INTERMOUNTAIN FOREST AND RANGE
EXPERIMENT STATION
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

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USER GUIDE TO HYDROLOGY

MINING AND RECLAMATION IN THE WEST

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RESEARCH SUMMARY

The hydrologist working on mined land must be aware of potential impacts of mining, as well as reclamation techniques available to him. This guide covers major points of concern to the hydrologist involved in planning for reclamation of mined land including: land-management planning and baseline data; soils and overburden analysis and sampling techniques; selecting storage areas; materials handling; spoils analysis; spoils problems/treatments; spoils surfacing; and monitoring and retreatment.

Information is presented in a question/rule/discussion format, and includes supporting graphic materials, notes on additional sources of information, a glossary, and an index.

ACKNOWLEDGMENTS

The contents of this guide are based on presentations and discussions during the Surface Environment and Mining (SEAM) sponsored Hydrology Workshop, March 21-23, 1979, Denver, Colorado. Credit is due all attendees and presenters for their input. Those who attended are listed in appendix B. In addition, major contributors are listed under chapter titles as appropriate.

A special note of thanks is extended to Earl F. Aldon, Ardell J. Bjugstad, Paul E. Packer, and Robert Partido, members of the cadre which planned the workshop. The workshop program coordinator was Edwin R. Browning (SEAM) and the technical adviser was Paul Packer.

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INTRODUCTION

MINERAL AND NONMINERAL RESOURCES

An adequate, reliable supply of minerals is essential to the economy and security of the United States, since minerals provide the physical basis for almost all activities of U. S. citizens. While imports can satisfy an important part of the country's minerals demands, they make the U.S. vulnerable to the economic and political decisions of foreign countries. Thus, the mineral deposits within the U.S. are a most important source of this nation's supply.

A substantial portion of the domestic minerals supply presently comes from lands managed by the Federal Government. Federal lands are known to contain a majority of the metallic minerals, as well as major resources of coal, oil shale, geothermal steam, uranium, and oil and gas. These same Federal lands, however, also contain valuable nonmineral resources, including timber, forage, water, wildlife, scenic landforms, and wilderness. The Government's holdings of such resources are now among the most significant in the world.

While it is clearly in the national interest to provide for the identification and production of the mineral resources on Federal land, it is also necessary to provide for a sustained high-level output of the various renewable resources on that land. Thus, the demand for mineral development must be balanced against the demand for renewable resources and the land-management agency's responsibility to reasonably protect the environment affected by mineral-related operations.

MINERALS IN THE LAND-MANAGEMENT PLANNING PROCESS

The Forest Service, as one of the agencies responsible for Federal land management, has a relatively sophisticated planning program for the management of nonmineral resources on land under its jurisdiction. Historically, however, the Forest Service's land-management and planning systems have treated minerals as a distinct category outside of the mainstream of the land-management planning process. There are two basic reasons for this separation:

1. The mining and mineral leasing laws have tended to make mineral activity the preferred use on any Federal land open to such activity. The thinking has been that on lands open to mineral activity, mineral development will generally override the designated primary nonmineral uses.

2. Planning for use of the mineral and nonmineral resources is complicated considerably by the difficulties of identifying and estimating the value of mineral resources. Mineral resources can be found only through costly and risky exploration. Therefore, land-management planning has tended to concentrate, at least until a mineral discovery is made, on the surface resource potential of the land.

The long-standing premise that mineral activity is always the most valuable use of a tract of land is increasingly being challenged. Many mineral deposits being discovered today are of lower grade, located at greater depths, and are therefore more expensive to find and mine than the high grade surface deposits formerly developed. Another significant factor is that nonmineral surface resources are not considered to be scarce, and their value has increased accordingly.

Hence, when all the mineral and nonmineral values are weighed for a particular proposal at a specific location, the value of the mineral resources may be outweighed by the value of the nonmineral resources. The process of weighing values usually occurs in an Environmental Assessment required by the National Environ-

mental Policy Act of 1969 (NEPA)[1] and is basic to determining the proper mix of uses for any given land area.

Given this situation of mineral and nonmineral values on the same tract of Federal land, decisions as to the proper use of a particular tract of land will always involve balancing the values of mineral and nonmineral resources. If this balancing is to be done in a reasonable manner, adequate information and analysis of all values are needed.

BACKGROUND: THE FORMATION AND MISSION OF SEAM

Realizing the complexity of such decisions, in 1973, the Forest Service chartered the Surface Environment and Mining program (SEAM) to coordinate research, development, and application related to land impacts resulting from minerals exploration and development in the West. From 1973 to 1979, SEAM sponsored more than 150 research and development projects. Together, the projects have greatly added to the body of knowledge surrounding the management of land in mineralized areas. (For purposes of this discussion, mineralized areas are defined as those areas that have some potential for mining.)

To get this knowledge to the specialists in the field in a form they could readily use, SEAM brought together researchers and users from industry, Federal agencies, and the academic community to share their practical knowledge and study results in a series of workshops. The information presented at these workshops is organized into five user guides. Each guide focuses on a specific discipline involved in managing surface resources that may be affected by mineral activities and is written for specialists in these disciplines. The guides will also be of use to land managers, land planners, and other specialists, since many activities related to minerals-area management demand that a variety of skills be applied to achieve an integrated approach.

In addition to the User Guide to Hydrology, guides have been written for vegetation, soils, engineering, and sociology and economics. Cross-referencing among these guides is provided in the index. A handbook for minerals specialists has also been written. A handbook for land managers will provide a general overview of administrative considerations surrounding mineral commodities commonly explored for and developed on national forest lands administered by the Forest Service. Concurrent with the development of the SEAM user guides, a USDA handbook on visual management related to mining and reclamation, entitled "Mining," is in press as volume 2 of the National Forest Landscape Management Series. A guide for the wildlife specialty is also planned. All guides will be updated periodically to keep them current with research findings.

The purpose of the guides is to help specialists more clearly understand their role in mineral exploration and development activities by outlining some of the major considerations they must address to insure that such activities integrate with land-management plans; that impacts are mitigated to a reasonable degree; and that reclamation meets state-of-the-art performance standards. Perhaps by using these guides as a common starting point, those involved in minerals management can more easily work together toward achieving these common goals: (1) appropriate consideration of minerals values in land-management planning; (2) protection of surface resources during mining activities; and (3) reclamation of surface-mined land to a productive use.

HOW TO USE THIS GUIDE

The chapters of this guide cover topics that concern the hydrologist during both land-management planning and any subsequent minerals activity. Within each chapter, major topics will be addressed in this way:

- Considerations: These are the questions the hydrologist should ask about each topic.
- Rules: These general statements answer the questions and direct the hydrologist toward the type of site-specific information the land

[1] U. S. Laws, Statutes, etc. Public Law 91-190. [S. 1075], Jan. 1, 1970. National Environmental Policy Act of 1969. An act to establish a national policy for the environment, to provide for the establishment of a Council on Environmental Quality, and for other purposes. In its United States statutes at large. 1969. Vol. 83, p. 852-856. U.S. Gov. Print. Off., Washington, D.C. 1970. [42 U.S.C. 4321, 433-4335, 4341-4347.]

manager may need to make decisions. Rules are set in italic type.

- Discussions: The discussions explain the reasoning behind the rules and in some cases give specific examples of how the rules are applied.
- Exceptions: Exceptions to various statements are given where applicable.
- Additional Information: Here the reader will find basic references to further information on the topic discussed.

The aim of this format is to help define the role of the hydrologist in minerals management. The guide is not intended to be a "cookbook" on rehabilitation techniques. Rather, it is intended to set up a logical thought process based on a question/answer approach. Such an approach allows for flexibility, eliminates unnecessary data gathering, helps simplify technical decisionmaking, and allows for a systematic documentation of the decisionmaking process. We hope that this organization of material will make the guides equally useful to users in industry, Federal and State agencies, and the academic community.

The role of the Forest Service staff is illustrated in table 1, "Stages of Mineral Exploration and Development Activities," and table 2, "Roles of Forest Service Specialists in Minerals Activities," which follow this introduction. As you will note, the Forest Service hydrologist will advise, review, and monitor. For example, although fisheries monitoring takes place during all stages of mining, the hydrologist will review these plans when the operating plan is submitted prior to development and, if necessary, suggest revisions to the plan to improve reclamation potential. Then, during mining and reclamation, the Forest Service specialist will monitor these activities according to the approved operating plan. In this way, the effects of the development will be managed in a proactive, rather than reactive mode. In other words, rather than reacting to crises, the hydrologist will be part of the forest's interdisciplinary (ID) team from the time land-management planning begins. Then, if and when mineral activities occur, the team will have foreseen potential problems and will have determined general rehabilitation objectives in advance.

Both land-management planning, in its broader application, and site-specific operational planning for mineral activities on National Forest System lands require the full range of interdisciplinary efforts so that information on both the mineral and nonmineral values can be presented to the decisionmaker in an integrated manner. The interdisciplinary approach to planning is uniquely suited to giving the best available assessment of the spectrum of opportunities and problems of managing surface resources that may be affected by mineral-related operations and the requirements needed for reasonable protection of nonmineral resources. Soils, vegetation, hydrology, topography, geology, wildlife, climate, and social and economic information are some of the factors that must be considered by the ID team.

Land management and planning must always proceed on the basis of existing information. In the case of mineral resources, this will almost always be difficult because the mineral resources are hidden beneath the surface and information is provided in increments as exploration proceeds. One of the principal goals of Federal land management, therefore, should be to improve such management by obtaining better mineral-resource information and integrating it into the decisionmaking processes.

When using this guide, the reader should keep in mind that, for the most part, the information is concerned with scientific considerations. While other factors, particularly cost and legal constraints, are a crucial part of the planning process, discussion of these aspects is limited here.

One final note: Successful rehabilitation is as much an art as a science. To clarify specific points or to keep up with new developments, readers are urged to contact the researchers who contributed to this guide or their regional reclamation specialists.

Additional Information:

For more information on the mining process, refer to "Anatomy of a Mine," USDA For. Serv. Gen. Tech. Rep. INT-35. 1977. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Table 1. — *Stages of mineral exploration and development activities*[1]

Prospecting	Exploration	Feasibility studies/operating plan
A. Administrative Action No administrative action required; however, some evidence of mineralization or a hunch	A. Administrative Action Permit/Lease Notice of intent from miner (for certain commodities, may also serve as operating plan if there is minimal surface disturbance) Exploration license EA may be necessary See Handbook for Land Managers (in press) for variation within commodities	A. Administrative Action Submission of necessary permits (EA etc.) and operating plan—see Handb for Land Managers (in press) for va within commodities
B. Activities Literature search Geological inference Evaluation of existing data Research on rights to land/minerals	B. Activities More intensive literature search Access road construction On-site testing and evaluation of data–geological, geochemical, geophysical, drilling, sampling, shaft sinking Seismic activity Acquiring land/mineral rights Rehabilitation of exploration impacts Environmental and socioeconomic studies	B. Activities Feasibility studies Grade and size of deposit Cost of mining and rehabilitation Market Fiscal Technical studies—mine design Environmental and socioeconomic stu (if not done during exploration) Decision to proceed with developmen Preparation of operating plan includir rehabilitation program and end use Ordering of equipment
C. Environmental Impacts Minimal, if any	C. Environmental Impacts Roads Drill holes Drill pads Dozer holes Exploration camps	C. Environmental Impacts Generally none at this stage
D. Tasks for the Hydrologist Establish baseline water-quality monitoring as needed according to plan	D. Tasks for the Hydrologist Review of plans to reclaim land impacted by exploration Review and assist in hydrologic aspects of environmental studies	D. Tasks for the Hydrologist Review adequacy of operating plan for: Hydrologic considerations— surface water subsurface water snow management roads impoundments mine drainage Hydrologic aspects of end use

[1] The various phases have considerable overlap. The material provided for each phase is illustrative, not complete, and consid variation is found by commodity. The existence of a forest plan is assumed. Tasks (D) are primarily input from a land-manag agency's hydrologist. For purposes of discussion, the terms reclamation and rehabilitation are used interchangeably, and m includes oil and gas activities.

Development[2]	Mining/reclamation	Postmining
A. Administrative Action Approval of necessary operating plan	A. Administrative Action No administrative action required. Mining overlaps with development and reclamation overlaps with mining; reclamation of previously mined areas occurs concurrently with new mining as stipulated in operating plan Any changes in operating plan	A. Administrative Action Release of reclamation bond
B. Activities Securing of financing More extensive testing and definition of the mineral Construction of transportation routes and utilities Construction of mine and processing plant (facilities, water supply, etc.) Construction of waste deposits Continued evaluation of data Change mining plan if necessary	B. Activities Extraction of mineral Processing of mineral Depositing wastes Operation of transportation systems Rehabilitation Monitoring for any changes in biological and physical environment Amend mining and rehabilitation plan if necessary	B. Activities Surface owner manages land after bond release Monitoring for any changes in biological and physical environment Management and maintenance for end-use objective
C. Environmental Impacts Mine Processing plant Waste dumps Transportation and access routes Utilities Increased population resulting from construction	C. Environmental Impacts Impacts directly related to operational aspects of mining; impacts are strongly affected by commodity mined and type of operation	C. Environmental Impacts Directly related to management and maintenance activities
D. Tasks for the Hydrologist Monitor impacts on hydrology	D. Tasks for the Hydrologist Monitor impacts on hydrology and hydrologic aspects of rehabilitation program Have hydrologic input into release of reclamation bond	D. Tasks for the Hydrologist Monitor any continued impacts on hydrology Manage hydrology for end-use objective

[2] Development is herein defined as the phase which begins after the right to mine has been established.

Table 2.—*Roles of Forest Service specialists in minerals activities*

	Prospecting	Exploration	Feasibility studies/operating plan
Vegetation specialist	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in vegetation aspects of environmental studies	Review adequacy of operating plan fo Reclamation program species selection plant materials site preparation planting methods cultural treatments Monitoring/retreatment program for vegetation Vegetation aspects of end use
Soils scientist	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in soils aspects of environmental studies Review soils inventory progress in the the mineralized areas; if needed, recommend timely completion or upgrading	Review adequacy of operating plan for Reclamation Program— soils surveys storage area selection materials handling plans spoils analysis plan spoils treatments spoils surfacing and erosion control Monitoring/retreatment program for sc Soils aspects of end use
Hydrologist	Establish baseline water-quality monitoring as needed according to plan	Review of plans to reclaim land impacted by exploration Review and assist in hydrologic aspects of environmental studies	Review adequacy of operating plan for Hydrologic considerations— surface water subsurface water snow management roads impoundments mine drainage Hydrologic aspects of end use
Engineer	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in engineering aspects of environmental studies	Review adequacy of operating plan for: Engineering considerations— air pollution transportation facilities surface-mine facilities mine-waste disposal embankments tailings dams and impoundments subsidence Engineering aspects of end use
Economist	Monitor factors which affect supply and demand for minerals Make forecasts of supply and demand Predict probability	Analyze costs and benefits of alternative exploration methods Participate with the sociologist in identification of existing and emerging issues	Provide expertise in environmental anal process: issue identification decision criteria cost/benefit analysis of alternatives tradeoff and opportunity-cost evalua Analyze effects of development on: demand for surface resources human behavioral patterns community economics
Sociologist	Identify the basic social/cultural descriptors of the affected communities Note current trends	Assist in structuring public involvement plan for appropriate: issue identification issue analysis mitigation action Identify critical trigger points from a social perspective	Provide expertise in environmental analy process: decision criteria issue identification Analyze effects of development on the cultural and political community Consider effects of alternative plans on social well-being

Development	Mining/reclamation	Postmining
Monitor vegetation impacts and activities for conformance to operating plan. Advise on plan revisions when necessary	Monitor vegetation impacts and activities for conformance to operating plan. Advise on plan revisions when necessary Advise from a vegetation standpoint on release of reclamation bond	Monitor any continued impacts on vegetation Manage vegetation for end-use objective
Monitor impacts on soils Monitor soils-related activites for conformance to operating plan. Advise on plan revisions when necessary	Monitor soils impacts and activities for conformance to operating plan. Advise on plan revisions when necessary Advise from a soils standpoint on release of reclamation bond	Monitor any continued impacts on soils Manage soils for end-use objective
Monitor impacts on hydrology	Monitor impacts on hydrology and hydrologic aspects of rehabilitation program Have hydrologic input into release of reclamation bond	Monitor any continued impacts on hydrology Manage hydrology for end-use objective
Monitor engineering-related activities for conformance to operating plan Advise on plan revisions when necessary	Advise from an engineering standpoint on release of reclamation bond	Monitor any continued impacts from engineered structures Manage structures for end-use objective
Record costs Monitor economic changes	Record costs Monitor economic changes	Monitor to determine accuracy of predictions for future use
Monitor Record changes Identify areas of individual or group stress relating to mineral activity and make recommendations to mitigate effects	Monitor Record changes	Monitor and record critical changes to establish new baseline situation

Chapter 1

LAND-MANAGEMENT PLANNING, EXPLORATION, AND BASELINE DATA AND THE MINING PLAN

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The hydrologist's role in mining operations begins before any mining activity occurs and continues during all the stages of mining, as well as after reclamation is complete and the bond released.

Because the hydrologic systems on a mine site can be affected during the very early stages of premining and exploration activity, the hydrologist's involvement actually begins even before interest in mining is expressed—during land-management planning. When exploration gets underway, his involvement increases. It is important to keep in mind that during mining, the hydrologist may not actively work with the hydrologic systems. The hydrologist, however, will be involved in reviewing mining plans and making decisions on their adequacy, so he must be knowledgeable about the conditions of the area and aware of what steps the mining operator must take to meet and maintain hydrologic standards.

This chapter looks at the early stages of the mining process—land-management planning, exploration, baseline data and the mining plan—and the role of the hydrologist in these stages. Remember that while the organization is roughly chronological, the stages are not clear-cut, and time overlaps may occur.

LAND-MANAGEMENT PLANNING

Long before a mining company expresses interest in a mineral deposit on land managed by the Forest Service, the land manager should know the area's potential for mining development, as well as its general reclamation potential. The hydrologist will play a key role in advising the land manager of the hydrologic impacts that may result if the area is mined, and of the area's reclamation potential. These considerations should appear in the general land-management plan.

Ideally, monitoring of hydrologic conditions begins during land-management planning. Budget and time restrictions, however, as well as the size of the area for which the hydrologist may be responsible, can make monitoring impossible at this time. Nevertheless, accurate and thorough hydrologic monitoring is essential over time for detecting changes in the hydrologic systems, taking mitigating actions to prevent damage to the systems, and maintaining hydrologic standards set by those governmental agencies regulating mining impacts. The hydrologist should be aware that, while standards are stated in terms of reclamation for soils and vegetation, for hydrology, standards address hydrologic conditions before, during, and after the mining process. The adequacy of a mining company's plan in addressing hydrology will be determined by the hydrologist, based on the information he has about the hydrology of an area, which may come from monitoring during land-use planning.

What is the role of the hydrologist in integrating hydrologic considerations into the land-management plan?

The hydrologist will be a member of an interdisciplinary (ID) team that will make recommendations on the land-management plan. If mining is a possibility, the hydrologist will provide information on the potential for protection or management of hydrologic values in the area during mining and their restoration after mining.

Discussion:

A high level of hydrologic information is usually not required during land-management planning, and the hydrologist is likely to rely on existing published and unpublished maps and surveys of the area or similar areas for information.

What hydrologic standards must be maintained during and after the mining process, and when are they set?

Hydrologic standards are set during land-management planning and, while specific hydrologic standards vary according to the mineral to be mined, and from area to area, the basic concept underlying all standard-setting is that the condition of the mined area should not be significantly different after mining than it was before. Thus, standards are designed to prevent the destruction of valuable aquifers and surface resources, as well as to allow mining companies to develop mineral resources. Hydrologic standards must be met for both surface water systems and subsurface water systems, so there is a need to relate the two.

Discussion:

Since standards will be site-specific, based on current land-management objectives and/or State standards, mining companies may consider requirements arbitrary and capricious because they differ from standards determined for a mining operation elsewhere or for other surface-resource uses. Presently, there are no specific guidelines for determining these standards, so a "reasonable" approach—one that protects valuable aquifers and surface resources and also allows for the development of mineral resources—should be taken. Eventually, a "reasonable" approach will be defined through the courts; however, until that time, Forest Service personnel involved in setting standards should maintain a written record of standards-setting procedures. This is so documentation of the process will be available if a court case is based on the procedure; under the new planning regulations, documentation on the part of the Forest Service is becoming important when legal issues arise. (See chapters 2 and 3 for specific hydrologic considerations in standards setting.)

Who sets hydrologic standards?

Agencies with the most authority to set hydrologic standards include the water-regulatory bodies of individual States; the Environmental Protection Agency, through the various States; Nuclear Regulatory Commission; Office of Surface Mining; and the Forest Service. Other government agencies may also develop standards related to the mining of specific minerals.

Discussion:

Though most hydrologic standards are set by agencies other than the Forest Service, the forest manager may determine at least some of the standards that should be met by mining companies; in these cases, the hydrologist will work with the forest manager to formulate the standards based upon identified needs.

What kind of hydrologic monitoring should be done during land-use planning?

Surface and subsurface water systems should be monitored in terms of water quality, the amount of water passing through the systems, who has the right to the water, and how mining might affect timing and delivery, water channels, lake shores, and lakes.

Discussion:

To determine whether a mining plan adequately addresses hydrologic monitoring, a hydrologist must have information about the condition of surface and subsurface water systems in an area, and this information, to be valid, must be collected over a long period of time. Thus, monitoring ideally begins during land-use planning. Climate variability, what is being monitored, and the reliability of the data being collected will determine the frequency of necessary monitoring.

EXPLORATION

Mineral exploration is the process of identifying and investigating "targets" in order to discover an economic mineral deposit. Exploration begins with regional studies that create little or no disturbance or occupation of the land. In addition to compiling existing geologic and photogeologic information, exploration also in-

volves geologic mapping and geochemical surveys. By the time a regional study has defined specific target areas, only a small portion of the lands originally considered is selected for more intensive study and exploratory work. At this stage, some land disturbance—drilling, for example—may occur.

Should a mineral deposit be found, the area of land involved is subject to more intensive exploratory work in a tighter pattern and is accompanied by more surface disturbance. If the exploratory work locates an ore body, development and mining are confined to an even more localized land area. Thus, a mining company's decision to explore an area for mineral deposits will require the land-management agency's personnel to become involved in a more intense analysis of the site than would normally occur during land-management planning.

How will the Forest Service hydrologist be involved with the mining company during exploration?

The Forest Service hydrologist will advise the mining company, through established agency procedures, of the hydrologic impacts of exploration and may or may not work with the mining company to collect data.

Discussion:

Early collection of hydrologic data on a potential mine site will help the hydrologist develop a data base for decisionmaking on the adequacy of mining plans and critical-area identification. As previously stated, hydrologic data must be collected over a long period of time to reflect such factors as seasonal variations. Working with mining companies to collect these data during exploration will increase the amount and extent of the data.

During exploration the mining company will be drilling to determine whether mineral resources exist and are minable. The hydrologist may be able to get water samples if an aquifer is tapped during drilling and he is working closely with the drilling crews. Also, the hydrologist may obtain information about rock strata from core samples, which could indicate an area's hydrologic suitability for mining, as well as information about the overburden.

Other kinds of information can be collected by the Forest Service during the drilling process, and the hydrologist may work as part of a team looking for several types of information.

Does the Forest Service have access to a mining company's data?

If a mining company has collected data about a leasable mineral, the company is required to give the Forest Service certain information about items such as mineral deposits. A prospecting permit may require the company to supply this information. A coal license absolutely requires this information of a mining company. For locatable minerals, any information collected is considered "privileged," and the company that collected it controls access to it.

Discussion:

Because mining companies have complete control of certain information they collect during exploration, prior data collection by the ID team is essential. The Forest Service should have information about every mine site on public lands, whether for a leasable or locatable mineral, because, in either case, it will be the responsibility of the Forest Service to insure that hydrologic conditions are not deteriorated or compromised during mining. In addition, a close working relationship between the Forest Service and the mining company, developed early in the mining process, can be beneficial to both parties since their combined expertise in data collecting can produce a more thorough data base.

BASELINE DATA AND THE MINING PLAN

Once exploration is complete and the mining company determines that it will mine the site, an environmental assessment may be in order and the formal gathering of baseline data to be included in the mining plan begins. Baseline data measure the conditions existing on the site prior to disturbance, help determine reclamation goals, and provide a basis against which reclamation success can be measured. Based on these comparisons, the mining operator may or may not be released from his bond of liability subsequent to mining and reclamation activities.

At this point, more specific information about the site may be needed to answer specific issues or management concerns identified in the

planning process. This information must be scientifically sound and well documented. In addition, ID team members should coordinate their efforts so that the data collected do not overlap.

General baseline data can be collected from field surveys as well as other sources of data, both published and unpublished, such as aerial photos and topographic maps. Information from these sources will generally include location of surface water features, topographic relief of the area being studied, aerial distribution of soils, surface geology, vegetation cover and distribution, magnitude and frequency of precipitation events, and stream flow and sediment discharge measurements. Further information must be acquired through monitoring.

The hydrologist will recommend to the land manager whether to accept, reject, or modify a company's mining plan, based on how the plan addresses hydrologic monitoring, and whether the company's plan includes measures designed to preserve hydrologic balances during the mining process and restore balances after the process is complete. The hydrologist may be responsible for proposing options to the mining plan either alone or as a member of an ID team. The land manager can request a periodic review of the plan during which changes can be made if: (1) mining processes are damaging hydrologic resources; or (2) only preliminary baseline data are included in the mining plan. To determine the adequacy of a mining plan's attention to hydrologic issues, the hydrologist must have valid data that have been collected over time, preferably showing seasonal hydrologic variations in the area.

What needs to be monitored and how often so that adequate hydrologic baseline data are collected?

The total ecosystem should be considered in monitoring and collecting baseline data. Such factors as water quality, delivery systems, channels, lake shores, lakes, how much water is passing through the system, who has the right to the water, and how mining will affect the timing, delivery, and total volume of water yielded from a natural system to one that is altered need to be inventoried so they can be evaluated according to their present condition and their condition over time. Climate variability, what is being sampled, and the degree of reliability of the data will determine those site-specific factors that should be monitored, and how frequently they should be monitored.

Discussion:

A conceptual hydrologic monitoring mo or system should be developed by the min company and evaluated by the hydrologist that all information collected is relevant; o that information that fits into the model ne to be collected. This is an extremely import step for industry, because some min companies collect too little baseline data, a some collect more than is necessary.

Who collects baseline hydrologic data?

Either the Forest Service or the mini company will collect the baseline data. Respo sibility for data collection will be negotiated tween the Forest Service and the mini company in each mining situation after explo tion is finished and the company has made t decision to mine.

Discussion:

When the mining operation will be on Fore Service land, it is the responsibility of the la manager to determine if the mining plan has adequate baseline-data design, and then if t data are collected according to the plan.

Although it is the responsibility of the Fore Service to insure that baseline-data requiremen are met by operators on Forest Service land, certain areas of the country, the Forest Servi is considering allowing State agencies to enfor their own State requirements on National Fore System lands because these regulations are least as stringent as Forest Service or Feder requirements. An example is the State Wyoming. In these situations, the Forest Servic will still approve mining plans and will retai authority over Forest Service lands.

In the case of small mine operators, extensiv data collection may be economically unfeasibl To aid these operators, Federal assistance can b applied for through the Small Operators Assis tance Program, Office of Surface Mining, U. S Dept. of the Interior. This program was estab lished by the Surface Mining and Reclamatio

Act of 1977 (P. L. 95-87, 30 U.S.C., Secs. 1201 et seq.).

Who must gather the hydrologic information for environmental assessments if they are required?

If the operation is located on national forest lands, the forest supervisor may be required to provide the information, in which case the hydrologist will probably be involved in data collection.

Discussion:

The Forest Service hydrologist may be actively involved in data collection, or involved only in review of the data, depending on who must supply the data. In either case, the same kind of information is needed.

Additional Information:

For more information on baseline studies, refer to "A Systems Approach to Ecological Baseline Studies," Biological Services Program, Fish and Wildlife Service, U.S. Department of the Interior, FWS/OBS-78/21, March 1978.

For more information about hydrologic data collection, refer to Barrett, James and others. 1979. "Procedures Recommended for Overburden and Hydrologic Studies of Surface Mines, Thunder Basin Project." USDA For. Serv. Gen. Tech. Rep. INT-71. (In Press)

Chapter 2
SURFACE WATER

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Management of surface water at a mining operation is a primary consideration for the hydrologist, for while he will probably not be directly involved in such management, he must be in a position to review their plans and advise the mining company on appropriate steps. Thus, he must be knowledgeable about surface water resources, and how mining may affect them, prior to commencement of the actual mining operation. It is essential that the hydrologist have an understanding of water movement over the surface and through the topsoil and spoils from a number of perspectives: designing techniques to establish vegetation, controlling erosion, stabilizing spoils, and controlling water pollution. In addition, since restoring stream channels and fisheries to the natural state is very difficult and expensive once they have been altered, the hydrologist must be aware of how the mining plan will affect these resources. One of his concerns is with the intended future use of the stream for fisheries, and whether efforts are being made throughout the mining phase to insure that this and other uses will be possible.

This chapter covers water flows, both overland and in streams, and considers hydrologic management techniques for both controlled and uncontrolled flows. Potential reclamation techniques are covered in a later chapter in this guide.

What factors determine the hydrologic behavior of land?

Two of the most important factors are precipitation and solar radiation. These are called "uncontrolled inputs" because they are not subject to management prior to their occurrence.

Discussion:

Both the seasonal amount of precipitation and the proportion of precipitation that occurs as snow have a significant effect on the hydrologic balance. In areas of the Western U.S. where surface mining occurs, average annual precipitation ranges from less than 10 cm in parts of the desert coal fields in Arizona and New Mexico to more than 125 cm in mountainous areas. At this time, more detailed information is needed about the amounts, intensities, and return frequencies of precipitation that can be used as a basis for conceptual hydrologic models.

Solar radiation affects the hydrologic cycle mainly through its influence on temperature. Air temperature is dependent on a number of factors included in the heat balance of an air layer near the ground. The aspects of temperature and radiation balance that are important from the hydrologic standpoint are the length of the growing season, potential evapotranspiration, the proportionate amount of precipitation occurring as snow, and the frequency of freezing and thawing (i.e., frost-free growing days).

Temperature fluctuations are especially severe throughout the Western mining fields, with average annual freeze/thaw frequencies ranging from less than 50 in desert sites of the Southwest to more than 250 on alpine sites. High freeze/thaw frequencies accelerate weathering of overburden materials, and this substantially affects infiltration characteristics. Slope steepness, spoil characteristics, and aspects have a significant effect on microclimates, and hence on hydrology. South-facing slopes receive more solar radiation, reach higher surface temperatures, and have higher potential evapotranspiration rates than do north-facing slopes. This difference can affect, both directly and indirectly, surface and subsurface movement of water over and through mined spoils. Mulch can be used to mitigate the effects of solar radiation

temperatures; and, as a preventive measure, the impact of solar radiation should be considered when dump locations are planned.

What is the impact of evapotranspiration on the hydrologic budget of mine spoils?

The hydrologic budget for a soil or spoil mass includes terms for precipitation input to the mass and water loss from the mass through evaporation, transpiration, and deep drainage. The interplay of these factors can have an ultimate impact on surface runoff at the mine site, depending on the balance between input and output of water. Evapotranspiration can be modified drastically by surface mining, and this modification can, in turn, substantially alter the surface runoff regime.

Discussion:

When annual precipitation is compared to the total potential evapotranspiration for areas ranging from arid to humid, the following principles apply:

- In arid regions, total potential evapotranspiration exceeds the precipitation by a considerable margin. Here, plant cover commonly uses all of the precipitation in evapotranspiration and leaves virtually none for deep drainage.
- In humid regions, total precipitation may equal or exceed potential evapotranspiration by a significant amount. Here, an excess of water beyond that required to satisfy plant growth and soil storage may occur. This excess will eventually appear either as surface water in the form of stream flow and/or as an increment to the ground water table.
- In areas where winter precipitation accumulates as snow or as soaking rains, there may be significant deep percolation, even though evapotranspiration exceeds precipitation on an annual basis.

The actual rate of evapotranspiration depends on climatic factors, soil/water content, the extent and type of plant cover, and land treatment and management techniques. Evapotranspiration can be modified significantly by removing or replacing vegetation during surface mining and reclamation operations. This can significantly change the surface runoff.

What is the significance of infiltration characteristics to the surface water regime in mined areas?

Infiltration is the basic precursor to overland flow and surface runoff. As snow melts or rain falls on soil or spoil materials, two important characteristics, infiltration and storage capacities, govern the amount of water that will enter and be stored in the soils and spoils. These characteristics exert a controlling influence on the eventual amount of surface runoff.

Discussion:

Major factors controlling infiltration are pore size and pore size distribution characteristics of the top few centimeters of the spoils, and the chemical nature of these spoil surface layers. Porosity characteristics of the surface, the kind and amount of vegetative cover, and the rate and amount of rainfall and snowmelt, as well as some of the physical, chemical, and biological characteristics of spoils that affect infiltration can be manipulated by man through agronomic and engineering practices. Other factors that determine the rate and amount of infiltration are slope steepness and orientation of the site surface.

Since surface-mining disturbance can increase overland flow (discussed later in this chapter) by decreasing the infiltration rate of spoils, it is important to understand characteristics of infiltration.

Slope steepness and orientation have a substantial but indirect effect on infiltration, and are important factors in mountainous areas of the West. Depression storage is generally greater on gentle slopes than on steep slopes and surface water is present longer after rainfall stops, providing greater infiltration opportunity. Therefore, spoil dump slopes should be as gentle as possible to enhance infiltration. The orientation of spoil dumps can affect infiltration by controlling the accumulation and melt of snowpack and repeated freeze/thaw cycling (see discussion of freeze/thaw rates earlier in this chapter).

Exceptions: There are two general exceptions to this: (1) Spoil materials that have not previously been subject to freezing and thawing because of their premining position below the soil surface tend to break down physically under such exposure. The

result is that smaller particles decrease the hydraulic conductivity more rapidly than do topsoil materials that have been previously repeatedly exposed to freezing and thawing. (2) Frozen spoils usually have a lower infiltration rate than unfrozen spoils. Spoils can be protected from freezing by temporary mulching or the rapid establishment of a protective cover of vegetation and organic matter.

Drastically reduced infiltration rates are common on spoils with pH's of much less than 5 or much more than 9; these limits are usually exceeded on heavy-metal mining sites and on sodic coal and bentonite areas. Where the surface layer or spoil is different from the underlying material, the top layer may have a saturated hydraulic conductivity that is less than that of the material below. In this case, infiltration is almost completely determined by the hydraulic conductivity of the surface layer and the storage capacity is determined by the hydraulic conductivity of the underlying material (hydraulic conductivity of any material is determined by volume and distribution of pore sizes). Where the top layer has a saturated hydraulic conductivity that is greater than that of the material below, infiltration behavior will still be largely determined by the hydraulic conductivity of the surface layer, and the storage capacity of the surface layer will depend on that layer's pore space storage characteristics. These spoil characteristics need to be known before spoil dumps are built, and in some cases may be learned from drill cores; however, they will primarily be learned by testing during overburden excavation. From a hydrologic point of view, the characteristics of the overburden layers need to be known so that advantage can be taken of them in sequencing materials into spoils to achieve the hydrologic objectives established earlier.

Infiltration generally has been described or predicted based on empirical equations or simplifications of general equations. Equations presented by Horton and Holtan are examples of empirical models. Equations obtained from simplifications of basic equations or algebraic approximations of numerical solutions to the basic equations have been given by Smith, Mine and Larsen, and Brustkern and Morel-Seytoux. The major stumbling block in estimating infiltration is the necessity of estimating parameters. Holtan and others have attempted to develop techniques for estimating parameters by using information available in soil surveys or by developing estimates of parameters for various land use or cover factors. Direct measurements of infiltration rates and capacities obtained from rainfall-simulating infiltrometers have provided valuable information concerning the infiltration characteristics of different kinds of land subjected to various treatments.

How does mining affect surface runoff?

Surface runoff begins when rainfall or snowmelt rates exceed the infiltration capacities of soil or spoil materials, or when the quantities of rain or snowmelt water have filled the storage capacities of the soil or spoil materials. Inasmuch as mining does alter the infiltration capacity of soil and its storage-capacity characteristics, it also influences resulting surface runoff.

Discussion:

Surface runoff can be classified as either overland flow or channel flow. A definition of overland flow is that which occurs outside of the well-defined and previously-existing channel system.

The mean velocity of overland flow is *directly* related to the slope for laminar flow and to the square root of the slope for turbulent flow; mean velocity is *inversely* related to the hydraulic resistance of the surface. In other words, the rougher the surface, the slower the flow.

Hydraulic resistance varies widely, depending on surface roughness characteristics, ranging from a Mannings n of .02 for bare soils to about .4 for a dense grass turf. Differences in hydraulic resistance of this magnitude from bare soil to dense turf will result in the depth of water on the rougher surface being approximately 6 times as great as the depth on the bare soils for the same discharge. The velocity of overland flow on rough surface soil would be only 1/6 of that on bare soil. Thus, the greater water depth on the rough, dense sod would allow much more time for infiltration after rainfall stops, resulting in less runoff, even if the infiltration characteristics

of the sod cover and the bare soil were the same. The lower velocities on the sod will also result in a much lower erosion potential. In many cases, surface-mining disturbance will increase overland flow by decreasing the infiltration rate and reducing the hydraulic resistance of the surface. Decreased infiltration and reduced hydraulic resistance tends to increase peak flow rates reaching stream channels.

Increases in surface runoff from various kinds of surface-mined disturbances in the West have been observed and measured. As an example, at one site, the overland flows from a spoil dump without any vegetation on it were compared. The dump had been prepared for revegetation; half of it was topsoil covered and half of it was raw spoil covered. On each half of the dump were a dozen plots extending the full length of the slope, each equipped to measure runoff and erosion. A storm at this site produced some .4 in. of rain in a few hours. It was observed that about twice the overland flow occurred on the raw spoils than on the topsoiled area, showing that the topsoil had better infiltration and storage characteristics. In addition, the sediment production off the raw spoils was 10 times that of the topsoil—that is, twice the runoff from the spoil materials produced 10 times the amount of sediment than came from the topsoil. This example provides an indication of the hydrologic advantages of topsoiling. (It should be noted that the preceding discussion represents only one observed example, and further research needs to be done to establish guidelines relative to length and steepness of spoil pile slope versus a design storm.)

What is the impact of surface water storage on overland flow?

Water can be stored on a soil or spoil surface as depression storage, within soil in an unsaturated condition, or in a saturated form where an impermeable barrier prevents or reduces the rate of further downward movement. All water that is trapped as depression storage either infiltrates or evaporates, with infiltration usually being greater. Within limits, rougher surfaces provide more depression storage. Depression storage may become surface runoff, however, when surface depressions overflow. This can quickly create a breakdown in the entire depression storage system and cause extensive erosion, a phenomenon that must be prevented on surface-mined areas.

Discussion:

Prevention or reduction of depression storage system breakdown can be achieved by increasing the amount of surface storage. This is done by keeping the gradient of spoil dump slopes gentle and the surfaces rough. A caution is merited, however, because the advantages of doing this—better erosion control and vegetation establishment—must be balanced against the dangers of allowing too much subsurface water buildup in the interior of spoil dumps, thereby creating a mass failure hazard.

How is erosion related to overland flow?

Erosion begins when raindrops strike soil or spoil surfaces and detach particles from them. The particles are then available for transport by surface runoff. Shear forces exerted by runoff may also detach particles, resulting in further erosion.

Discussion:

On short slopes of perhaps no more than 100-200 ft in length, raindrop splash erosion is most significant. On longer slopes and in snowmelt situations, rill erosion as a result of overland flow becoming concentrated is more significant. Exceptions to this depend greatly upon stability characteristics of the soil and spoil material and steepness of the slope. Except for arid desert areas in the West, most of the erosion caused by overland flow is generated by snowmelt runoff, which occurs every year. Thus, bare soil areas should be protected by surface mulches and vegetation as soon as possible. Also, sediment basins should be designed to handle the larger quantity of snowmelt runoff that is anticipated. Where rainfall, rather than snowmelt, is the primary cause of erosion by overland flow, sediment basins should be designed to handle the high-intensity, short-duration rainstorm events that are expected.

What is the role of overland flow in chemical pollution of water from mine sites?

Chemicals dissolved in water will ordinarily move at approximately the same rate as the water, if the chemicals are not too highly reactive with spoil materials. Generally, anions,

such as chloride and nitrates, fall in this category. If, however, interactions occur between the dissolved chemicals in the spoil materials, many complex situations may occur. For example, cations such as calcium, magnesium, potassium, sodium, ammonia, copper, iron, and cobalt are highly reactive and will readily exchange on and off the spoil cation exchange sites.

Discussion:

A major effect of surface mining is the potential for concentration of salts and heavy metals in the runoff water, and thus, its potential impact on downslope and downstream water uses. In many cases, chemistry of mine spoil materials is such that soluble salts can keep overland flow water, and even stream flow below the spoil, near saturation with concentrations of saline, alkaline, acid, and heavy metal cations that are damaging or even lethal to terrestrial and aquatic biological organisms in their path. The concentration of heavy cations in water depends to a large extent upon the pH levels of the water, a partially-manageable spoil characteristic.

Additional Information:

For more information on chemical site preparation of soils and spoils, see "User Guide to Soils," INT-68.

For more information on equations, refer to:

Horton, R.E. 1940. An approach toward physical interpretation of infiltration capacity. Soil Science, Society America Proc. 5:399-417.

Holtan, H.N. 1961. A concept for infiltration estimates in watershed engineering. USDA Agric. Res. Serv. 41-51, Washington, D.C., 25 p.

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Mine, R.G. and C.L. Larsen. 1973. Modeling infiltration during a steady rain. Water Resources Research 9(2):384-394.

Brustkern, R.L. and H.J. Morel-Seytoux. 1970. Analytical treatment of two-phase infiltration. J. of Hydrology Division Proc. American Society of Civil Engineers 96(HY12):2535-2548.

STREAMS

Streams, defined as concentrated flows of water moving in a definable channel or natural drainage system, will be considered in this section. The hydrologist should keep in mind that streams need not be on mine sites to be affected by mining activity; rather, the local geology and land form of the area will determine the kinds of impacts a mine will have on on-site, as well as off-site, streams. Any type of vegetation removal, soil compaction, increase in slope gradient, and/or construction is likely to increase the volume of flow and rate of delivery or response time—the time it takes for water to move from spoils into a channel. These factors may also increase sediment loads, chemical or soluble loads, and peak flows (fig. 1). The most obvious effects of mining on stream flow occur as a result of such activities as construction of roads, pits, and dumps or terraces that intersect a natural drainage system. Indeed, roads may have a greater impact on the surface water flow than the active mine situation itself in terms of volume of flow, the number of drainages that are intercepted, and the total area disturbed. The hydrologist should be aware that any impacts on the channel surface or the water quality also impact the stream's aquatic environment.

This section examines some of the factors hydrologists should consider when faced with questions concerning stream characteristics.

What factors influence the physical stability of a stream channel?

The physical stability of the stream channel is a function of the texture, structure, and chemical nature of both the side and bottom materials of the channel together with the expected peak stream flow rate.

Discussion:

The stability of the channel will be affected by the gradients and the alignment of its boundaries. It is predictable that changes in the volume or rate of flow of water through the channel will impact sinuous streams more highly than straight channels. Moreover, engineering attempts at straightening stream channels to solve stability problems have been only partially successful to date. In addition, abrasion or corrosion of the sides and bottom of stream

Figure 1. Sediment load and movement in streams can be altered by mining activities and damage or destroy fisheries.

channels can be caused by erosion, which is a result of hydraulic action of the water or waterborne particles. Channel erosion may also be caused by chemicals present in the water (fig. 2).

What is the role of sediment basins in maintaining water quality in streams?

Sediment basins can serve to prevent degradation of water quality caused by sedimentation in the stream channels.

Discussion:

Sediment basins, while being of greatest use during the time between when mining starts and total revegetation of the area is completed, can continue to be useful following these measures, particularly if the stream flow regime in small watersheds is changed by mining. Presently, it is felt that the data base for the proper design, operation, and maintenance of sediment basins should be expanded to avoid failure in the basins.

How can in-stream problems be minimized?

The most important step in minimizing in-stream problems is to have a complete enough data base to be able to anticipate the types of problems that will occur at the mining site. This will enable the hydrologist to advise the mining company on how to design the mine or the water flow system to handle the expected problems. In addition, when problems are anticipated, the hydrologist can suggest several alternatives for solving them. Alternatives may be biological, which usually implies a long-term solution that may require maintenance; or problems may be solved through engineering design.

Figure 2. Bank slumpage, characteristic of stream instability, can be caused by erosion from the hydraulic action of water or chemicals dissolved in water.

Discussion:

A number of techniques are available to the hydrologist for helping to minimize in-stream problems. Foremost among these is enlisting the advice of an expert in river and stream mechanics. Economic constraints should always be considered in suggesting these techniques; however, in light of the maintenance/reclamation goals of the mining plan, these may be considered as possible alternatives for minimizing in-stream problems:

• Occasionally, it is beneficial to divert water from one natural channel to another. While this should be a last alternative because of its impact on the channels and fisheries, it is still useful when needed. For example, when roads are being built, water is often diverted from one drainage intercept to another. Diversions can also be used to route off-site water around disturbances and mine dumps, rather than allowing it to run through the disturbed area.

• Buffer strips can be used to prevent excess water and sediment from being dumped into active water channels. For instance, such strips are utilized on the Caribou National Forest, where any surface disturbance within 200 feet of a stream that has been designated as a high-value fishery is prohibited. Buffer strips should be used wherever needed. Guides are available for developing buffer strips along logging roads, and these could probably be adapted to mining situations.

• Engineering-type structures, such as energy dissipators and settling basins can be used to reduce sediment load. Technology is available for removing chemical loads from water, but the costs can be prohibitive, particularly at high-elevation or abandoned mines. Moreover, there

is no clear-cut definition of who is responsible for removing the pollutants.

• Stream channels can be stabilized by a variety of techniques—rip-raps, drop inlet structures, bank stabilization—which can be accomplished at the time slope gradients and stream bank slopes are changed, and vegetation is reestablished. Optimally, stream channel stabilization would be achieved by a combination of revegetation and engineering techniques.

STREAM FISHERIES

How does mining affect stream fisheries?

Mining can affect fisheries by widening or filling in stream channels, diverting stream flows, increasing suspended sediments and dissolved solids, disrupting stream banks, increasing sediment bedloads, eliminating or changing riparian vegetation species composition, and adding toxic elements to the water.

Discussion:

Monitoring the effects of mining on a fishery is difficult because the interactions between mining and the fishery are complex. Nevertheless, there are suitable monitoring systems in use that provide the necessary information to evaluate the effects on fishery habitats of management activity, in this case, mining. In dealing with fisheries on mining-impacted areas, the hydrologist should call on biologists to assist in suggesting the best methodology available. Legally, the Forest Service can use State and Federal water-quality regulations, as well as its own standards, to protect fisheries from mining impacts.

What should stream monitoring for mining impacts on fisheries include?

All four components of the aquatic system—stream-side vegetation, channel morphology, shape and quality of the water column, and the soil portion of the stream bank—should be monitored over time.

Discussion:

Stream monitoring may be a simple two-station operation—one above the mining activity and one below; or an elaborate network of many stations may be needed. The method selected will depend on the extent of anticipated hydrologic impacts from the mine, the overall hydrology of the area, and the nature of the surface water system. Fish are excellent monitoring tools because they are indicators of present aquatic conditions.

Stream-side vegetation. Certain types of stream-side vegetation biomass can be determined by using an electronic digital herbage recorder or by weighing. Occular estimates of biomass weight can also be useful, but accuracy requires continual training of the estimators checked against actual weights. Stream-side vegetation, along with undercut banks and stream-side debris, provide fish cover and stabilize water temperature. Vegetation also provides habitat for terrestrial insects, an important part of the fishes' diet. If stream-side vegetation is eliminated, so is a large segment of the fishery, regardless of excellent water quality or channel conditions.

Stream channel morphology. This can be monitored by using freeze method or core-type substrata samplers, which are fairly effective. Tract sediment and deposition can be monitored with transects and measuring rods. Substrata movement can be monitored with a chain system or other devices that indicate channel gradation or degradation (fig. 3).

Water column shape and quality. Standpipes are used to measure subsurface oxygen, subsurface water flows, and subsurface permeability (fig. 4). A thermister is an excellent temperature monitoring device for this. Occular measurement systems are now used to monitor stream channel changes, although observation error and repeatability are problems with this method. If measurements are large, however, the occular method is sufficiently accurate. High-quality water is essential to the survival of fish. While lethal levels of heavy metals and acid produced by mines can be easily monitored using standard methods, incipient lethal levels—amounts less than 10 parts per billion—are difficult to monitor. Current monitoring methods do not indicate incipient lethal levels, avoidance levels to fish, or obscure levels that react over long periods of time.

Soil portion of the stream bank. Cross-

sectional stream bank profiles are one of the better monitoring methods for the soil portion of the stream bank; stream bank stability, and vegetative cover and vigor ratings also help monitor stream bank conditions.

Since stream fisheries are complex environments, and specialized knowledge is required to manage them effectively, the hydrologist should seek the assistance of a fisheries biologist when working in this subject area.

Figure 3. Chain systems can be used to monitor substrata movement.

Figure 4. Standpipes are used to measure subsurface oxygen, subsurface water flows, and subsurface permeability.

Chapter 3
SUBSURFACE WATER

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Management of subsurface water is an important consideration during the mining process, both in terms of mining's impacts on existing subsurface water systems and in terms of systems that may develop as a result of mining activities. While the hydrologist probably will not be directly involved in their management, his knowledge of the potential impacts of mining on these systems can insure that proper management plans are included in the mining plan.

What information does the hydrologist need to describe a ground water system?

To describe the ground water system for a mining area in detail, information about the geology of the site and aquifers present on the site is needed. This can be obtained from existing information and wells, additional well samples, and installing new wells.

Discussion:

Aquifers must be identified early in the mining process. Information about aquifers in the overburden, aquifer recharge and discharge, hydraulic connection among aquifers, and the importance of the ground water resource is needed. Information about the geology of the mining area can be obtained from geologic maps, drilling information, testing of piezometric surface levels, and other geologic studies.

If water balances, dissolved solids balances, and the hydraulic properties of aquifers are understood, generally the ground water system is understood. Water level fluctuations indicate recharge and discharge activity in aquifers. Fluctuations can be measured by placing a recorder on a well to obtain water levels, which are then correlated with precipitation events.

The interchange between ground water and surface water should also be considered in conjunction with aquifer recharge and discharge. The hydraulic connection between streams and aquifers often occurs through the alluvium, since an alluvial aquifer is usually associated with a stream. Aquifer interaction with streams can sometimes be identified through measurements of the piezometric surface levels and the water table in relation to stream levels. If the piezometric surface and the water table tend to come together near the streams, an interaction is indicated, and stream elevation is controlling the piezometric surface level near the stream. Gains and losses in stream discharge can sometimes be measured, if differences are large enough. If the chemistry of the ground water is different from the chemistry of the stream water, monitoring water above and below the mine site for the chemical content can indicate any chemical changes, and, thus, can be used to estimate relative recharge and discharge.

Aquifers do not always behave independently and water may move from one to another. Such interchange should be identified because mining impacts on one aquifer could also affect others.

The degree of importance of ground water resources should be assessed according to present and potential uses of the aquifers. In cases where ground water quality is so bad that the water is not usable for anything, consideration of ground water resource should be different than where a ground water resource is either very important or a potentially important component of the water supply.

What impact does mining have on subsurface water?

If an aquifer supplying recharge to streams is disrupted by mining, the base flow contribution

to streams will be affected through changes in both the quality and supply of ground water to streams. Changes in ground water flow patterns and an altered water table or piezometric surface can also result from mining.

Discussion:

Changes in ground water quality. During mining, percolating water may come in contact with mineral surfaces, which could increase levels of dissolved solids, and/or trace elements in the ground water. Also, ground water quality can be altered by input of water percolating from mine pits, shafts, and tailings impoundments. Since the amount and quality of recharge to the ground water supply can be altered by mining, the ground water supply to streams may also be altered, which can affect the condition of fisheries.

Changes in flow patterns. The hydraulic conductivity and transmissivity of material backfilled into a disrupted aquifer will usually be different than the material that was there before the aquifer was disturbed, and changes in flow patterns should be expected to occur. This will produce two effects, both of which can be calculated. If the spoils have a higher hydraulic conductivity than the existing aquifer, there is a tendency to increase ground water flow through the spoils area. On the other hand, if the spoils have a lower hydraulic conductivity than the existing aquifer, there is a tendency for water to flow around the area.

Mining can also affect the recharge and storage capacity of an area. When impervious rock strata above an aquifer are shattered by mining, the resultant spoils can store more water and also act as a new recharge area.

Lowered water table or piezometric surface. By putting a pit or a shaft into an aquifer, a pressure sink can be created and the water table or piezometric surface that exists prior to mining can be lowered. The effects of this can be measured, further and further away from the mine site over time. For example, artesian wells away from the mine site and springs important to wildlife can begin to dry up.

Ground water mounds may form beneath settling and tailings ponds and increase the elevation of the piezometric surface in these areas. This may result in high subsurface ground water conditions, an increased downslope hydraulic gradient, and an increase in slumping activity.

SMALL DISCONTINUOUS GROUND WATER SYSTEMS IN MOUNTAINOUS AREAS

Ground water systems may develop in mine dumps located on steep slopes in mountainous

areas and contribute to stability problems. The ground water systems are not always perennial; rather, they often occur in the spring, during peak snowmelt periods. The main source of water for the system is usually snowmelt, although there may be a significant lateral contribution to the system from side slopes on the surrounding terrain. When ground water systems occur in the dumps, saturated hydraulic conductivities develop throughout the affected area of the fill. Stability problems usually occur within 4 or 5 ft of the mining surface and instability is usually apparent within 3 years of dump construction; however, the accuracy of prediction of dump instability is not high with our current level of knowledge.

How can mine dump instability caused by small discontinuous ground water systems in mountainous areas be avoided?

There are a number of engineering and reclamation techniques that can be used to avoid mine dump instability.

Discussion:

Perforated steel pipes or a French drain can be installed during dump construction as a passive drainage system to remove ground water from the slopes before slumping occurs; this has been done on the interstate highway system from Maine to Oregon. Passive drainage systems can also be installed on slopes with existing problems. Another construction technique, though it has economic limitations, is dump foundation construction, which includes compacting the bottom layers of fill. Also, surfacing mining dumps with materials that allow for minimum infiltration may minimize ground water problems, though this will increase surface runoff.

Tying mining waste dumps into native terrain, especially at the toe of the slope, should be done carefully. This is a common practice that often results in a mismatch of hydraulic conductivities between the spoils and the soil beneath. Sufficient passive drainage (French drains, for example) should be installed where such mismatches occur in order to insure effective drainage of the mine dump before it becomes mass unstable. Dumping spoil on vegetation can result in a slippage plane when the vegetation rots, so the dumping site should be scalped first. Planting woody, deep-rooting vegetation removes some of the excess water through transpiration and thus allows for more storage capacity during the recharge season. Furthermore, the deep roots tend to bind the surface or the upper layers of the spoil together, thereby promoting stability.

Chapter 4
SNOW MANAGEMENT

Chapter Organizer: Eugene Farmer

Major Contributors: Eugene Farmer, Robert S. Johnston, Ronald D. Tabler

Management of snow in mined areas becomes a topic of concern for the hydrologist in a number of situations. First, of course, is the consideration of whether or not snow distribution is a problem in the mining area. If it is, as determined through observation as well as measurement, then consideration must be given to how snow can affect the mining operation in terms of distribution, spoil/snow interaction, runoff, impacts on and benefits to reclamation, and access to the area. Major snow-related considerations are discussed further in this chapter.

How does the hydrologist determine whether snow distribution is a problem in the mining area?

The hydrologist should rely on the premining survey and inventory, as well as general knowledge of the area, in deciding whether snow is a problem.

Discussion:

Mining plans should include information on the winter climate: seasonal snowfall and precipitation water-equivalent, wind speed and direction, temperature (monthly means, maximums, and minimums), and the distribution of snow by wind. Snow drifting patterns should be documented by both aerial and ground photographs taken at monthly intervals throughout one or more winters. Snow profiles of major accumulation areas at time of maximum accumulation should also be included.

Wind direction prevailing during the drifting season (if any) can be determined from the aerial photographs, and from ground observations of drifting patterns, snow particle abrasion of posts and exposed rocks, and "hedging" of vegetation.

How will snow distribution affect mining operations?

While impacts are site-specific, effects will be elevation-related, leading to different problems on the plains than in mountainous mine sites.

Discussion:

Snow distribution patterns reflect the interaction of seasonal snowfall amounts, topography, vegetation, wind, and air temperatures. Snow distribution should be considered of major importance in areas where blowing and drifting snow are common features of the winter climate. Snowdrifts can block access roads and generally impede mining operations.

Another problem that must be considered is soil erosion generated by melt from drifted snow. Surface runoff from rapid melting of these drifts may result in rill and gully formation. Saturation of dumps, resulting in slumping or mass failure, may also occur. This is particularly true on mines located in mountainous terrain. Both of these occurrences may contribute to sediment loads in streams. Finally, irregular, old dump sites may increase snow retention, resulting in too much water being held within the waste materials.

Two possible solutions exist for these problems. First, in areas where snow drifting is determined to be a problem prior to mining, proper mine design may be effective in reducing snowdrift accumulation. Second, if the mine already exists and has not been designed to mitigate snowdrift problems, methods are available for manipulation of snow movement on-site.

What are the most effective methods of controlling snow deposition?

The most common methods of controlling

snow deposits are snow fences and other artificial barriers (fig. 5). Other techniques include manipulation of the terrain (shaping), and management of the surface roughness.

Discussion:

Properly designed snow fences can provide effective protection against snowdrifts, or they can be used to store large volumes of water to augment local water supplies for irrigation or other uses. (Figure 6 shows how to determine volume of water stored.) The keys to successful snow fence systems for preventing drifts include: (1) sufficient *capacity* to store the predicted seasonal snow transport; (2) the use of *tall* fences in preference to multiple rows of shorter structures; (3) proper *fence design*; (4) proper *placement* in relation to the protected area; (5) the use of *long* fences (greater than 30 times the fence height); and (6) *orientation* perpendicular to the prevailing wind.

Snow transport water-equivalent, q (in ft^3 of water per foot of fence length) can be estimated from

$$q = 5000\ P_r\ (1 - 0.14^{0.0001R})$$

where P_r is relocated precipitation (feet, water equivalent) and R is the "fetch" or contributing distance (feet). This method is described in the reference by Tabler (1975a). For 50-percent porous fences on level terrain, the maximum water-equivalent capacity of a snow fence having height H is approximately $10H^2$. From these relationships, then, it is possible to determine the required fence height. Construction cost per unit volume of snow storage decreases with increasing fence height, so it is less expensive to build a single row of 12-ft-tall fence, for example, than 4 rows of 6-ft fence having equivalent capacity.

Proper fence design includes 50-percent porosity, a bottom-gap of 0.1H, and the use of horizontal slats having widths less than (approximately) 8 inches. A 15° inclination from verti-

Figure 5. Snow fence.

cal, downwind, also increases capacity by about 25 percent. Engineering drawings for effective snow fences are given in Tabler (1974).

The maximum length of the lee drift behind a full fence is 30H, so fences should be placed at least 30H upwind from the area to be protected.

Snow fences for protecting transplanted shrubs and augmenting soil water should be shorter, or more porous, than those used for drift prevention. Fences that are 2 ft tall, spaced 60 ft apart, will provide a relatively uniform snow cover on level terrain. On windward-facing slopes (greater than about 10 percent) or on ridge crests, however, spacing should be reduced by about half in order to achieve a uniform snow distribution. Fencing that is 4 ft high, having about 75-percent open area (porosity) will also result in a sufficiently shallow, uniform deposit, at least on level terrain. Again, spacing should be about 30H, or 120 ft for a 4-ft fence.

The most economical method of snow management for augmenting soil water, however, is through manipulation of surface roughness rather than the use of artificial barriers. In general, mined areas should be left with as rough a surface as possible, to provide numerous depressions for snow retention. Contoured furrows, ripped strips, terraces, and pits or gouges are all preferable to smoothly graded and harrowed surfaces; however, careful contouring of two-dimensional roughness features is essential to avoid gradients that might induce gully formation.

Benefits of rough surfaces include retention of rainfall as well as snow, reduced evaporation, protection against abrasion by wind-blown soil and snow particles, shading, and reduced wind and water erosion. Rough surfaces are gradually smoothed out by weathering processes over the course of the few years needed for successful establishment of vegetation.

Another possible method for controlling deposition of wind-transported snow is through appropriate shaping of the terrain. The method

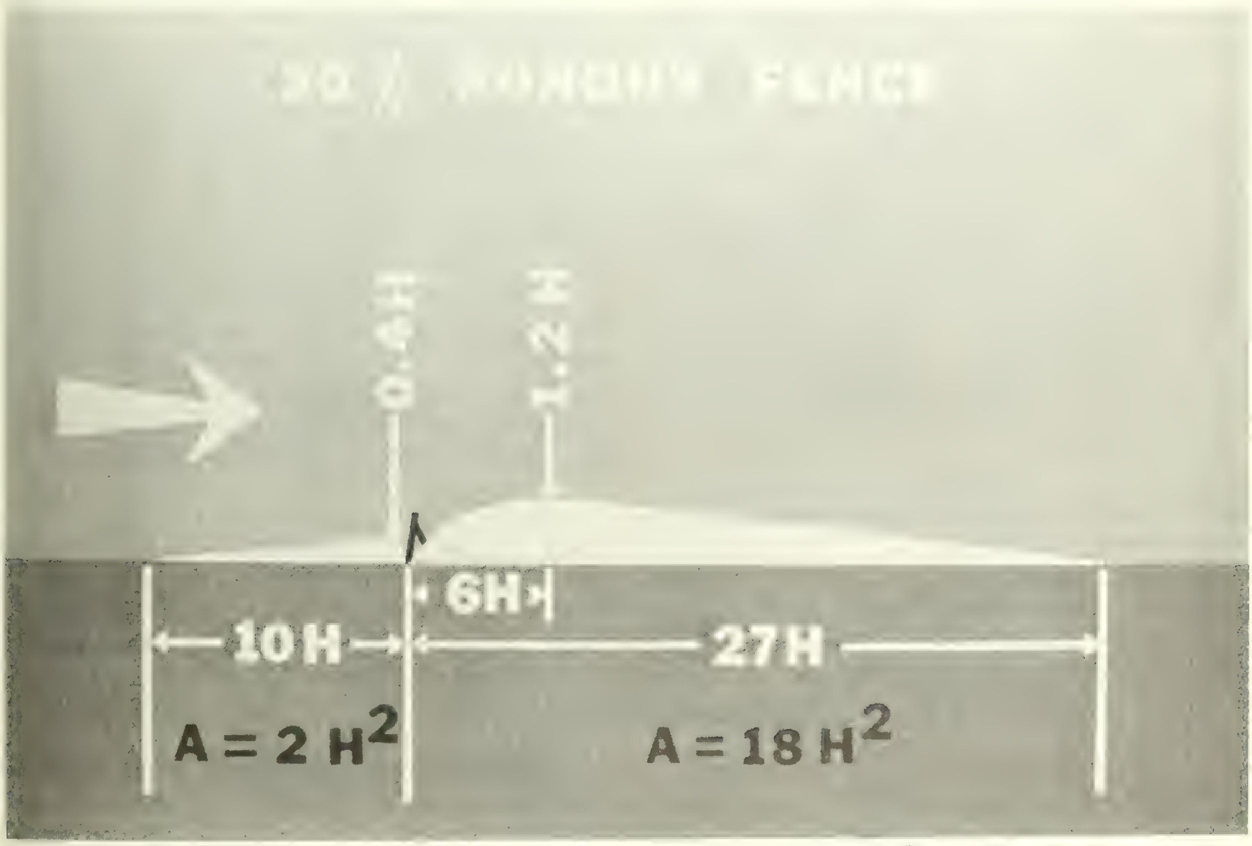

Figure 6. Ideally, a snow fence is 50-percent porous; a simple equation—10 x H^2 (height of the fence)/lineal ft of fence—can be used to determine approximately the volume of water stored behind a snowfence.

described by Tabler (1975b) can be used to predict snow accumulation in various terrain configurations, allowing design of drift-free roads and shaping of terrain to optimize snow distribution to facilitate revegetation.

Additional Information:

For further information on snow fences, refer to:

Tabler, Ronald D. 1973. New snow fence design controls drifts, improves visibility, reduces road ice. Annu. Transp. Eng. Conf. (Colo. Univ., Denver, February 1973) Proc. 46:16-27.

Tabler, Ronald D. 1974. New engineering criteria for snow fence systems. Transportation Research Board (National Research Council) Trans. Res. Record 506:65-78.

Tabler, Ronald D. 1975a. Estimating the transport and evaporation of blowing snow. p. 85-104. *In*: Snow Manage. on Great Plains Symp. (Bismarck, N. Dak., July 1975) Proc. Great Plains Agric. Counc. Publ. 73, 186 p.

Montagne, John, J. T. McPartland, A. B. Saper and H. W. Townes. 1968. The nature and control of snow cornices on the Bridger Range, Southwestern Montana. USDA Forest Service, Misc. Report No. 14. Alta Avalanche Study Center, Wasatch National Forest.

For further information on terrain shaping, refer to:

Tabler, Ronald D. 1975b. Estimating the profile of snowdrifts in topographic catchments. Proc. West. Snow Conf. 43:87-97.

Packer, Paul E. 1971. Terrain and cover effects on snowmelt in a western white pine forest. Forest Science, Vol. 17, No. 1, March, pp. 125-134.

What impact does snow contaminated by mining have on water chemistry?

Snow contamination may occur hand-in-hand with acid mine drainage, when oxidation of sulfide minerals occurs. The symptom of this is that metallic concentrations and the mass flow of metals in streams increase during peak snowmelt periods.

Discussion:

Snow contamination occurs via two sources: (1) the incorporation of reactive dust within the snowpack itself; and (2) the capillary suction in the snow/ice matrix at the snow/ground interface.

In snowpacks 5-6 ft deep near high-altitude heavy-metal mines, as many as half a dozen layers of dust materials can be seen. When analyses are run on the contaminated material, it is found to consist primarily of sulfide minerals with a pH of between 2 and 3. This material does not contribute any acid load itself, because oxidation of sulfide minerals is a chemical reaction and is affected by the temperature surrounding the reaction. In a snowpack 32°F or colder, this reaction proceeds very slowly, and is not a source of acid production until the snowpack melts and the material is deposited on the surface. Then, during the summer warm period, the reaction occurs and sulfuric acid is produced. The amount of dust incorporated in the snowpack is variable and depends on what the source of the dust is and how it is measured. For example, in two mines, where the walls are very steep, deposition of as much as a ton of dust per acre over a winter is possible near the margins of the pit.

Regarding capillary suction, the snow/ice matrix acts like a sponge in picking up acid products from the surface of the soil. As snowmelt proceeds and the snowpack starts to bleed snowmelt water, the initial flush will have a metallic ion concentration up to 30 times greater than succeeding increments of snowmelt. The first increment acts as a concentrating mechanism. Thus, during periods of peak snowmelt runoff, a direct relationship exists between stream flow volumes and metallic ion concentrations. How far the ions are sucked up into the snowpack depends on the matrix at the snow/soil interface, but at one mine the height was as much as 15 cm.

How can snow contamination be prevented on mine sites?

Two measures are helpful: (1) minimizing dust production at the site as much as possible and (2) reducing the acidity on the surface.

Discussion:

Opportunities for reducing dust production are limited at an open-pit site. One possible method, however, is to eliminate any dump faces that might be blown free of snow or become wind-scarred during the wintertime.

Revegetation appears to be the key to solving the problem of acidity reduction. The spoil material should be topsoiled and vegetation established so the sulfide particles cannot be moved, thereby reducing exposure of new surfaces and decreasing the opportunities for oxidation of these sulfide materials to produce acid.

Note:

The problems discussed in the section on snow contamination may be important at some sites. The most important principle, however, is that snowmelt water provides the excess water for flushing the products of oxidation and heavy metals that have accumulated in the spoil materials.

Chapter 5
ROADS

Chapter Organizer: Ed Burroughs

Major Contributor: Ed Burroughs

The hydrologist will provide input about the hydrologic impacts of mining roads during their design, construction, and maintenance. Even before construction gets underway, however, he should be aware of potential problems, and be able to advise on mitigating actions during his examination of the mining plan.

While the topics addressed in this chapter are particularly concerned with roads constructed for a mining operation, it should be remembered that many times mining roads are used for other forest operations—timber harvesting, for example. Therefore, the hydrologist can generally draw upon principles learned from other types of operations in solving mining-related road problems.

What is a mine road?

Mine roads may be quite large—as much as 60 ft or more in width—with a ditch and a berm. They are high-standard roads, are compacted and made of dense material in order to sustain traffic of 200 tons or more. In some cases, forest roads (those typically found in Forest Service operations) will be used for mining purposes.

Discussion:

Of concern to the hydrologist is the fact that since a large impermeable area is created by the road, water will run off rapidly during intense storms. Even the smaller roads found at some mine sites are still fairly impermeable, and thus, may have the same problem on a smaller scale. When water runs off at the berm, which is looser, an additional source of sediment is created.

What are the major hydrologic impacts of mine roads?

The major impact of roads on the surface water resource is concentration of runoff and resulting sediment yields. A minor effect of roads on the water resource is caused by fugitive dust settling on vegetation and soil adjacent to the stream channel where it can be washed into the stream by rainfall or snowmelt. Another minor impact is the damming effect of roads, which causes an impediment to subsurface flow under the roads.

Discussion:

In some mining situations, such as large coal operations in the Northern Great Plains, the total impact of roads may appear to be relatively minor compared to the impact of the entire mining operation. The impact, however, can still be significant, and must not be overlooked. In other mining areas, such as the Overthrust Belt from Utah to Canada, where intensive oil and gas exploration is occurring, the impact of the extensive network of access roads may be much greater, compared to the size of the rest of the operation.

Fugitive dust is basically an engineering problem, and while the hydrologist may not be called on to deal with it, he should nevertheless be aware of the consequences.

The damming effect of roads occurs when a fill is being constructed over slopes and shallow soil mantles. Water that would normally go over the bedrock under the road no longer can because of compaction of the material, which changes the hydraulic conductivity of the material under the road.

How much sediment will a road produce?

This question should be addressed in two parts: (1) sediment produced by road cuts and fills; and (2) sediment produced by the road surfaces and ditches.

Discussion:

Road cuts and fills. The hydrologist has a number of tools available for estimating the impacts of cuts and fills. One of the best is a report by the National Transportation Research Board (under the National Academy of Sciences), which uses the Universal Soil Loss Equation as a basis for estimating soil erosion from cuts and fills. The method takes into consideration rainfall intensity, rainfall energy, soil, slope length, and gradient in both a vegetated and unvegetated condition.

This information is best used to estimate the relative differences in treatment to stabilize road cuts and fills so that alternatives can be developed. For example, suppose two treatments, A and B, are under consideration. Treatment A would yield 200 lb/acre of soil loss; treatment B would yield 375 lb/acre of soil loss. In terms of accuracy, the relative estimated difference between the treatments is more accurate than the absolute estimate of the soil loss from either treatment. In other words, there is more confidence in the 175 lb/acre difference than in the estimation of sediment yield for either of the two treatments themselves.

When using the Universal Soil Loss Equation, the hydrologist should keep in mind that reservations as to its complete accuracy have been expressed, for four major reasons. These are: (1) The Universal Soil Loss Equation does not provide any satisfactory way to handle the snowmelt water component, and it is estimated that as much as two-thirds to three-fourths of mine-dump erosion in Western mountainous terrain occurs as a result of snowmelt. (2) Sufficient testing of K factor values of mine spoils has not yet been done to merit assurance of the accuracy of the values, so these should be used cautiously. (3) The equation is not designed to handle gully erosion; rather, it is designed to handle only sheet and rill erosion flows. (4) The Universal Soil Loss Equation is designed to be an average annual estimate, not an estimator related to a single storm event.

Road surfaces and ditches. While a predictive model exists for estimating soil erosion from road surfaces and ditches, there is not yet a reliable method for tying the model to actual events. The predictive model is called the Road Sediment Model (ROSED), and was developed by the USDA Forest Service Rocky Mountain Forest and Range Experiment Station at Fort Collins, Colorado. The model is designed to estimate the runoff hydrograph based on given rainfall conditions and soils information pertaining to infiltration. It will estimate runoff and sediment by time increments so that a sediment concentration curve can be built. The model is also designed to predict sediment yield by size classes.

It should be noted that, while the theoretical portions of the model have been developed, at this time, there has not yet been a reliable confirmation of the model's accuracy through testing it against actual storm events. Data collection and analysis, however, are proceeding, and the results of these endeavors should be available in 1980. Therefore, a discussion of the use of ROSED is included here.

In order to use this model, the hydrologist should find a road in the area similar to the planned road. Measurements should be taken for such factors as densities, particle size, and gradation to develop an estimate of what the infiltration will be. In addition, available loose soil on the road surface must be estimated, and again an analogous road can be used for doing this. Surface roughness must also be estimated, and according to the ROSED, roughness has two major components: grain resistance to flow, which is particle-size graduation of surface material, and form resistance to flow, which is caused by the rock surfacing that is put on top of the material. Presently, techniques are being developed for the hydrologist to use in estimating form and grain roughness for a planned road.

No matter what prediction model the hydrologist is using, he will have to determine the most significant erosion-generating climatic event. This depends on area of the country, of course. For example, in the Southwest, the intense thunderstorms will probably generate the most significant amount of erosion. At low-to-moderate elevations, the rain-on-snow event may be most significant, while the intense snowmelt season at high elevations will generate the most erosion.

What can be done to mitigate impacts caused by roads?

A number of techniques exist, including control of culvert discharge and installing sediment

onds below large fills or points where ditch dis-harge is dumped.

Discussion:

On the smaller forest roads, refer to "Guides or Controlling Sediment From Secondary Logging Roads" (see Additional Information) on sing obstructions to cause sediment deposition elow culvert outfalls. On larger roads, the roblem is more complex because the level of nowledge is still slight. It is known, however, hat in addition to controlling culvert discharge n these roads, road cuts and fills can be revegetated, and downspouts can be installed below ulverts.

On wide roads, sediment ponds below large lls or points where road ditch discharge is umped can be helpful. A short course offered y the University of Kentucky at Lexington ulls together available technology for design of ediment ponds in terms of detention time, spillway design, and so forth, which may be of value o the hydrologist. A similar course is offered at Oregon State University.

Since sediment-carrying water is commonly iverted off mining roads and into streams, conderation should be given to finding ways of eeping such sediment-laden water out of treams. This might be accomplished by breaking up the drainage off roads and by installing more frequent drainage points so that the olumes of water coming off at any one point re not great enough to flow into streams. Planting vegetation at runoff points can help to dissiate the flow; however, the hydrologist must lso consider the timing and the quality of the ediment entering stream channels where sheries exist. In general, while the sediment eeds of fish are site-specific, during periods of igh water flow, fisheries can tolerate more sediment than during low flows. For example, uring the summer, a low-flow period, when ediment comes off a road system into a fishery, here may not be sufficient power in the streams o move the sediment that settles on top of pawning areas or drain areas. Thus, although it s generally desirable to keep as much sediment s possible out of channels, this goal must be alanced against the needs of the fishery for ediment. The hydrologist should be involved in eview of the operating plan to insure that standards for sediment control at fisheries are set properly to accommodate these needs.

When should the hydrologist be concerned with mass erosion problems caused by roads?

In areas where heavy snowpacks occur, where very intense snowmelt rates occur, where ground water is accumulated, or where steep slopes and shallow soils exist, stability problems become significant. The hydrologist will be called on to walk proposed road locations to help identify potential stability problems.

Discussion:

In areas where mass slope failure is common, the hydrologist must become proficient at identifying those portions of the watershed that may become unstable as a result of road-building. The key is to learn to identify areas of the terrain where ground water concentrations can occur. These may be in ephemeral channels next to a ridge; in small bowl-shaped depressions (headwalls); in very steep slopes, in very shallow soils—in other words, points where ground water can accumulate either as a result of rainfall or snowmelt or both.

A model has been developed for the Oregon Coast ranges to predict ground water rise in feet for storms of various given intensities. While this model has not yet been widely-tested, it does offer a method for developing regional ground water prediction equations for other areas.

Instability indicators can be found on the ground, as well as by consulting topographic maps, geologic maps, and area photographs. A source of information on slope stability is a publication put out by the Oregon Bureau of Land Management "Slope Stability and Road Construction." Once unstable areas are identified, experts such as materials engineers or engineering geologists can be called upon to make a detailed examination on the ground.

Additional Information:

For a summary of the National Transportation Research Board's report, refer to: "Highway Erosion Control System: An Evaluation Based on the Universal Soil Loss Equation," by Gene Farmer and Joel Fletcher. Reprint from Soil Erosion Prediction and Control, Soil Conservation Society of America, p 12-21. 1976.

For more information on the Road Sediment Model, refer to: "Formulation of Road Sediment Model," by D. B. Simons, R. M. Li, and I. Y. Shiao. Publication No. CER 76-77DBS-RML-LYS50. Colorado State University, Civil Engineering Dep., Engineering Research Center, Ft. Collins, Colo. 80523.

For more information on using obstructions in sediment control, refer to: "Guides for Controlling Sediment From Secondary Logging Roads," by P. E. Packer and G. W. Christensen, Intermountain Forest and Range Experiment Station, Ogden, Utah, and Northern Region, Missoula, Mont. 1967.

For more information on the University of Kentucky's short courses on impoundments contact: Dr. B. J. Banfield, Dep. of Agricultural Engineering, University of Kentucky, Lexington, Ky. 40506.

For more information on slope stability, refer to: "Slope Stability in Road Construction," U.S. Dep. of the Interior, Bureau of Land Management, Oregon State Office, P. O. Box 2965, Portland, Ore. 97208.

"Landslide Hazards Related to Land Use Planning in the Teton National Forest, Northwest Wyoming," by Robert G. Bailey, USDA For. Serv. Intermountain Region. 1971.

Chapter 6
EFFECTS OF RECLAMATION ON SURFACE WATER

Chapter Organizer: Paul Packer

Major Contributors: Robert S. Johnston, Paul Packer

In chapter 2, hydrologic processes and components that are affected by mining were discussed. This chapter looks at these factors again, this time in light of management steps that can be taken to mitigate the effects of surface mining disturbance on surface hydrologic behavior. Within limits, the hydrologic regime of an area disturbed by surface mining can be modified by practices that alter hydrologic transmission rates and/or storage capacities. These practices include management of topsoiling, surface configuration, subsoil layering, mulching, and vegetation, and are discussed in this chapter.

In general, what is involved in carrying out reclamation to maintain or improve surface water?

Reclamation can be either preventive or corrective. Preventive reclamation is predictive—that is, hydrologic disturbance as a result of mining is predicted according to known principles, and solutions, both biological and engineering, are specified in the planning stage. Corrective reclamation takes place as unpredictable events affecting the hydrologic system occur throughout mining.

Discussion:

Anticipated problems associated with surface water and mining should be considered in the mining plan. Based on similar mining situations, both the problems and likely successful solutions to those problems can be included in the plan. Predictable problems include channel erosion, stream bank and channel instability, degradation of streams, aquatic community problems, and water quality, in terms of both sediment and chemical composition.

Catastrophic events, however, which will require corrective reclamation, are usually accidental or are acts of nature and cannot be predicted. When confronted with such events, the hydrologist, working with other members of the ID team and the mining company, will be in a position of recommending mitigating measures. Thus, his knowledge of the hydrology of the site, as well as general hydrologic principles, should enable him to suggest alternatives for dealing with both the expected and unexpected problems.

Specific techniques for carrying out reclamation to protect surface water follow.

What effects do topsoiling or surfacing have on surface water reclamation?

There are two major purposes for topsoiling a spoil area: (1) to provide an acceptable growth medium for plants; and (2) to provide better infiltration and less surface runoff of water—and, hence, less erosion.

Discussion:

Adding topsoil is important in heavy-metal mining areas in the West where acid drainage is encountered with surface mining. Wind and water erosion constantly renew the supply of pyritic material for oxidation and hydrolyzation to form sulfuric acid. Placement of a layer of topsoil at least 30 cm thick is effective in reducing the acid formation rate by preventing further erosion of the pyritic surfaces, by reducing the oxygen supply available to the pyrite, and by reducing the amount of water moving through the pyritic layers. Where highly sodic spoils occur, surfacing with more neutral materials usually benefits the surface runoff quality. In general, then, when a good growth medium can be placed on top of the spoil in acid- or sodic-producing areas, better runoff quality can be achieved. In spoil materials that do not contain toxic materials, surfacing with topsoil is still highly desirable in order to pro-

vide improved infiltration and water-storage capacity in the spoils, thus helping to reduce overland flow and its attendant erosion hazards and promote revegetation efforts.

Exception: On steep slopes, spoil materials that are higher in rock content tend to form rock pavements and prevent further erosion. Topsoils that are lower in rock content do not form pavements as readily and may erode more extensively.

How can surface configuration be managed to improve the hydrologic characteristics of mining spoils?

Both the macro- and micro-topography of surface-mined areas can be modified to increase depression storage, reduce slope length, and eliminate ponding of waters. All are desirable.

Discussion:

Increasing depression storage increases infiltration and decreases direct surface runoff and, thus, erosion. Reducing slope length greatly decreases the concentration of surface runoff; both slope gradient and slope length of many mine spoil areas can be reduced to the point that almost all the water that accumulates from storms is retained. Changes in surface configuration can also affect redistribution of snow in areas where drifting snow creates water stresses on mine spoils, or where retaining snow might be desirable and useful in providing water for vegetation.

In humid areas, which, in the West, are the mountainous snowpack areas, surface configurations that conserve much of the water may cause other problems more serious than those caused by the runoff and erosion that result if the water is only partially contained. When large amounts of water are contained on the slopes, either by high infiltration capacities or in contour trenches, the danger of mass landslides can be increased. This is particularly true in areas where the normal hillside slopes are steeper than 30 percent. Such mass instability can aggravate surface instability, causing increased erosion and deterioration of water quality through sedimentation.

Terracing systems on steep spoil dumps in humid areas help to prevent severe rill and gully erosion by reducing the effective slope length. The water discharge from the terrace chann[...] must be conveyed off of the slopes by mean[...] stabilized outlets or subsurface drains. The ch[...] disadvantage of such terrace systems occ[...] where deep winter snowpacks develop, beca[...] during the spring, when alternate freezing a[...] thawing take place, ice tends to develop [...] terraces. In this case, terraces may not drain [...]fectively and water either percolates back in[...] the spoils, aggravating internal water problem[...] or overtops the terraces, producing serious [...] and gully erosion.

In arid regions, terracing at strategic locatio[...] can be advantageous, serving both to discoura[...] runoff concentrations where it is not desirab[...] and to concentrate water into control are[...] where it can be used to maintain plant grow[...] In other words, surface configuration can [...] used to harvest water for enhancing revege[...]tion.

How can subsoil layering be used to improve th[...] hydrologic characteristics of mining spoils?

During spoil-dump construction and backfi[...]ing after surface mining, materials can [...] sequenced in layers to modify the hydrolog[...] behavior of the areas involved.

Discussion:

When surface layers are coarse and have a lo[...] water-holding capacity, this capacity can be i[...]creased to aid revegetation by placing a com[...]pacted or restricting layer just below the plan[...] root zone. Similarly, compacted layers that re[...]strict water flow can be placed above high[...] sulfide materials, to restrict oxidation an[...] hydrolyzation of the sulfides. Effective use o[...] subsoil layering to achieve specific hydrologi[...] objectives requires complete knowledge of th[...] infiltration and hydraulic conductivity charac[...]teristics and behavior of different overburden[...] materials. Some knowledge of the chemical com[...]position of these layers is also essential.

How can mulching be used to alter the surfac[...] hydrology of mined land?

Mulches can be used to: reduce evaporation[...] allowing water to remain near the spoils surface[...] for a longer time, thus enhancing the oppor[...]tunity for seedling survival during revegetation[...] intercept raindrops, thus protecting surfaces[...] from puddling and splashing; reduce the velocity[...]

of surface runoff, and thus surface erosion, by increasing the infiltration opportunity time on the spoils; insulate soil surface to prevent excessive high surface temperature; and prevent soil freezing.

Discussion:

Reduction of heat energy on the soil surface from solar radiation can be positive or negative. On north-facing slopes, such reduction can cause soil to remain cold during the spring, thus delaying or reducing seedling germination. However, heat reduction can sometimes enhance the growth of seedlings by preventing soil from drying out. Differences in the temperatures of soils caused by differences in materials color can also be minimized by use of mulch.

In some instances, mulches can increase the total infiltration capacity sufficiently to enhance the leaching of salts out of the surface spoils materials, which can prepare the surface for better early plant growth than is possible without mulch. This is especially true on oil shale, and may be true on some highly sodic coal areas.

The use of mulches for erosion control on mine spoils during the time it takes to establish a plant cover is most effective where spoil dump slopes are in excess of about 30 percent. As slope steepness decreases below 30 percent the value of mulches strictly for erosion control drops off rapidly in relation to their cost.

How does vegetation affect the surface hydrology of reclaimed mine lands?

The amount and kind of vegetation cover protecting spoils is an important determinant of the infiltration, surface runoff, and erosion behavior of mined lands, as well as hydraulic resistance of the surface to overland flow.

Discussion:

In selecting species to plant on surface-mined areas, an important factor to consider is the ability of the plants to grow under the local conditions. The next consideration should be the effectiveness of the vegetation for water control. Control can usually be achieved more quickly with grass or mixed plantings than with shrubs and trees alone.

The rooting depth of vegetation has a significant effect on the surface hydrology in arid and semi-arid climates where shallow-rooted vegetation is often subjected to water stress. Overland flow will be greatly decreased and total runoff will be somewhat decreased if the watershed is covered with deep-rooted vegetation than if covered with shallow-rooted species. Most important, however, is the plant basal area and litter density for control of overland flow. This becomes especially important where surface-mined areas to be revegetated comprise substantial proportions of water-yielding watersheds.

How can the hydrologic consequences of mining reclamation be evaluated?

Very little research has been done on the hydrologic effects of surface-mine disturbance and reclamation. The research that has been done has, to some extent, developed ranking criteria for some limited aspects of hydrology, particularly surface hydrology. Studies, however, have not yet been designed to produce information that can be integrated into a quantitative prediction model useful in designing management procedures for specifying hydrologic goals on mined land.

Discussion:

The evaluation of the hydrologic consequences of surface mining and reclamation activities on surface-mined lands requires procedures that quantitatively predict a flow or storage component of a hydrologic cycle for various alternative practices. Quantitative evaluations require the development of models of water, chemical, and sediment transport on disturbed and rehabilitated areas; other models must represent descriptions of how water, chemicals, and sediment move under alternative management systems or practices. These models must observe the basic physical principles of hydrology and also incorporate the principles of chemistry, biology, and plant science needed to describe a biological system. Out of necessity, these models also must include a number of empirical laws or considerations and require extensive field data.

What assistance is available to the hydrologist involved in surface water reclamation?

The hydraulic engineer, forest engineer, and regional hydrologist, as well as regional engineers, consultants, and university specialists, can assist with surface water reclamation.

Discussion:

While the hydraulic engineer will not necessarily have specific knowledge of soil/plant interaction, his expertise may be more valuable to the hydrologist during this stage of mining than that of other types of engineers. The hydrologist can rely on the hydraulic engineer, in additio to Forest Service specialists and research person nel, consultants, and university specialists, fc information about innovative reclamation tech niques, both tested and untested, in a specifi area.

Chapter 7
SUBSURFACE WATER MANAGEMENT AND TREATMENT

apter Organizer: Eugene Farmer

ajor Contributors: Eugene Farmer, David B. :Whorter

In general, very little can be done during the clamation phase of mining regarding ground ater. It should, however, be remembered roughout the mining process—including recla- ation—that what is done regarding surface ater directly affects subsurface water, though ere may be a time lag involved in the manifes- tion of the effects. As emphasized previously, e hydrologist must be aware of potential im- cts on subsurface water before mining actually ts underway. Then, during mining reclama- on, his major role is to monitor certain factors/ tivities that were identified during the plan- ng phase as potential problems; be aware of ssible problems that might occur as a result of neral reclamation activities; and advise the ning company of steps it can take to mitigate rmful impacts. This chapter summarizes sub- rface water treatment concerns the hydrol- ist should be aware of, and possibly have to ake recommendations on.

hat aspects of subsurface water management d treatment should the hydrologist be con- rned with during reclamation?

Before and during reclamation, the hydrol- ist may be involved in predicting and estima- g what the long-term ground water chemistry ill be; permanent changes in aquifer flow tterns; recovery time and equilibrium levels of e piezometric surface and water table in mined eas where water has been withdrawn from the t; and whether permanent changes may occur the water balance. He will also be concerned ith mine dumps and tailings impoundments as they affect subsurface water, and monitoring of these effects of the system (see chapters 8, 9, and 10).

Discussion:

In general, the hydrologist should, on a site-specific basis, take actions before the reclamation phase to protect certain valuable subsurface water resources. For example, the hydrologist may determine that mining will disrupt an aquifer that is the only good source of water for farming in the area. In this case, he should make recommendations to prevent deterioration of the aquifer or to guarantee its restoration. Possible recommendations he could make include installing a cutoff wall of clay or grout, or compaction of backfill to prevent destruction of the aquifer, or reconstruction of the aquifer through selective spoils placement.

The key word for the hydrologist to keep in mind in dealing with subsurface water considerations during reclamation is "site-specific." For example, it is very difficult to predict long-term changes in ground water chemistry that may result from mining, since no standard methodology exists for making such predictions. Thus, the hydrologist must apply what he knows about the site itself in predicting changes as accurately as possible, and recommending mitigating measures, if they are necessary.

Permanent changes in the flow patterns in aquifers become significant on a site-specific basis, as determined by the end-use, as well as the original quality, of the aquifer. It is assumed that some permanent changes in the water balance will result from mining activity, if the system is reasonably large. The relative magnitude of the system determines whether these changes will negatively impact the planned end-use of the area. If so, then measures to restore the balance, insofar as possible, must be recom-

mended by the hydrologist early in mining activity.

What problems associated with small discontinuous ground water systems in mountainous terrains can be managed during reclamation?

The major problems with these systems occur when the top few feet of spoil material slide off of rehabilitated areas. During reclamation, installation of drainage systems can help alleviate this problem.

Discussion:

Ideally, the development of these systems and the problems associated with them can be anticipated, and preventive steps taken early in the mining process. Passive drainage systems (those that require no maintenance), can be installed as the waste dumps are being rehabilitated. In addition, materials allowing for proper infiltration can be used to surface mine dumps and snow accumulation on the mining area can be discouraged to reduce snowmelt, and thus infiltration.

Additional Information:

On design and spacing of drainage systems, refer to: "Analysis of Parallel Drains for Highway Cut-Slope Stabilization," by Rodney Prellwitz, Geotechnical Engineer, USDA For. Serv., Region I, Missoula, Mont.

For further information on ground water, refer to the EPA series of publications "Monitoring Groundwater Quality," by Todd, Tinlin, Schmidt, and Everett, EPA-600/4-79-019, 026,036.

Chapter 8
ACID MINE DRAINAGE

hapter Organizer: Dale Ralston

ajor Contributors: Eugene Farmer, Dale alston

During mining, ground and surface water ow systems may be modified or created that low for acid production caused by an increased vailability of water and oxygen to acid-roducing mineral surfaces. Reclamation, then, volves controlling and/or modifying these flow stems.

In any mining situation, acid production is lated to the amount of exposed surfaces of id-bearing rock, occurring primarily in the few p centimeters of the surface exposed to oxy-n or oxidizing compounds. Then, acid is trans-orted by weeping or flushing of oxidized metal lts in the mine. (Weeping occurs underground a result of constant dripping of poor quality ater. Flushing—the biggest problem in acid ine drainage—occurs when water flows through e mine, taking with it the acid salts formed nderground, then drains into surface or sub-rface water systems.)

In abandoned or existing mines, acid mine ainage problems cannot be entirely solved, but ey may be reduced by as much as 80 percent ith proper management. Acid drainage that es reach streams can be treated through exist-g technology; the major limitation is cost.

In new and operating mines, preplanning can fectively limit acid mine drainage problems roughout the mining process. The costs of acid ine drainage control and specific techniques at can be used to limit acid production should considered early in the mining process. Suc-essfully limiting acid production will require e hydrologist's input throughout the entire e-cycle of the mine; historically, however, this s not been done.

What factors are associated with the occurrence of acid mine drainage?

For acid mine drainage to occur, iron sulfide (generally pyrite), oxygen, moisture in the mine atmosphere, other heavy metals, available water for recharge, and the physical characteristics of the mine itself must interact to produce acid and then allow it to drain from the mine.

Discussion:

These variables are the same for both surface and underground mining, and as long as they are present, there will be acid mine drainage (fig. 7). Elimination of any of the variables will eliminate acid production.

Generally, moisture in the mine atmosphere and the presence of iron sulfide and other heavy metals are uncontrollable factors and govern the production of acid in the mine. Following mining, residual iron sulfide and other heavy metals are generally still present, so accordingly their effectiveness for producing acid remains. Water in mines is difficult or impossible to eliminate; in deeper mines there is generally 100-percent humidity.

The amount of oxygen can be severely limited by flooding the acid-producing area of the mine; limiting oxygen by sealing the mine alone is generally unsuccessful.

Available water for recharge and the physical characteristics of the mine *are* controllable and govern the recharge or flushing effect of water. Without water for transport, the production of acid in mines will not impact areas surrounding the mine.

What data are needed for identification of acid mine drainage problems?

In order to identify acid mine drainage problems, the hydrologist must have data collected over time on: the amount and quality of discharge from portals; the spatial variations of

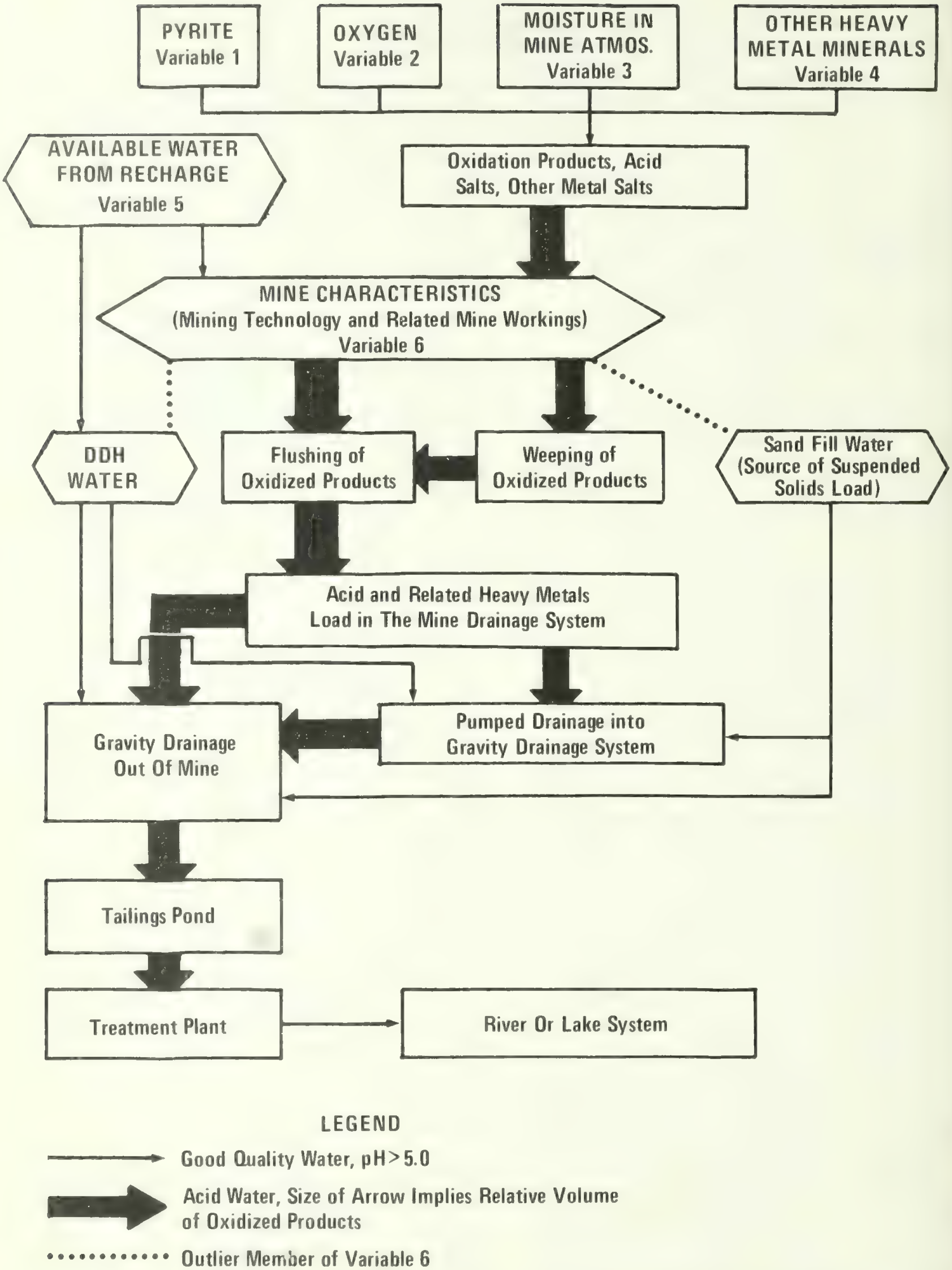

Figure 7. Variables in production of acid mine drainage. (Idaho Bureau of Mines and Geology, Moscow).

vater quality and discharge underground; characteristics of the underground workings of the nine; the mineralogy of the mine; and possible ources of acid-drainage—the mine, waste lumps, other mines close by.

Discussion:

The most extensive data collection period hould be during spring runoff.

Discharge from portals and underground hould be described over one hydrologic cycle, o that variations can be identified.

Underground characteristics of the mine, the umber of levels, number and location of raises o the surface, vents, stope areas where ore has een removed, waste deposits, surface waste deosits, and near-surface features (caved areas and ncreased vertical hydraulic conductivity) should e identified. Mining companies generally have his information, as well as information about he mineralogy of the site.

The source of the acid drainage should be arefully identified through testing of discharge rom various mines, waste piles, and so forth, nonitored over time.

low can acid mine drainage problems be classiied?

Acid mine drainage problems can be classified ccording to their characteristics, and fall into our categories: (1) a mine with direct surface echarge and major acid production; (2) a mine vith direct surface recharge and minor acid proluction; (3) mine drainage occurring from interepted premining ground water flow systems vith major acid production; and (4) mine drainge occurring from intercepted premining round water flow systems without major acid roduction.

Discussion:

A mine with direct surface recharge and najor acid production can be identified by mine lrainage hydrographs indicating peak acid conent coincident or nearly coincident with runoff or snowmelt events, and poor water quality that aries throughout the year. Lower concentraions of acid in mine drainage will occur during he fall and winter; the highest concentration vill occur during peak flow discharge; the lowest oncentration will occur immediately after the eak runoff event; and high concentrations occurring after peak flow will gradually decrease during the summer.

A mine with direct surface recharge and minor acid production will be characterized by mine drainage hydrographs with peak acid content coincident or nearly coincident with runoff or snowmelt events, and water quality that varies as described above except that the concentrations of metals vary from low to very low.

Mine drainage that may occur from intercepted premining ground water flow systems with major acid production is characterized by mine drainage hydrographs that are subdued and lagged replicas of local runoff, and water quality that varies directly with flow—for example, higher acid concentrations will occur with higher flow.

Mine drainage that may occur from intercepted premining ground water flow systems without major acid production is characterized by mine drainage hydrographs as described above, and water quality that varies with flow, but acid concentrations are low to very low.

What techniques can be used to solve acid mine drainage problems in abandoned or existing mines?

Three basic techniques are available; these are to: (1) reduce discharge and improve water quality; (2) maintain discharge and improve water quality; and (3) reduce discharge but not improve water quality. The techniques used to solve an acid mine discharge problem will depend on the specific problem being treated.

Discussion:

Reduction of mine discharge can be accomplished by reducing direct water recharge into mine workings and by reducing drainage into the mine from intercepted ground water flow systems (fig. 8).

To reduce direct recharge into mine workings, points or zones of water entry into the mine must be identified (stopes near the surface, raises or vents, caving areas, and open pit areas). Then, water movement into the mine areas must be reduced by: (1) constructing diversion structures to prevent overland flow from entering mine workings; (2) sealing raises and vents down to solid rock to limit shallow ground water movement into the mine; (3) regrading where possible to eliminate depressions caused by

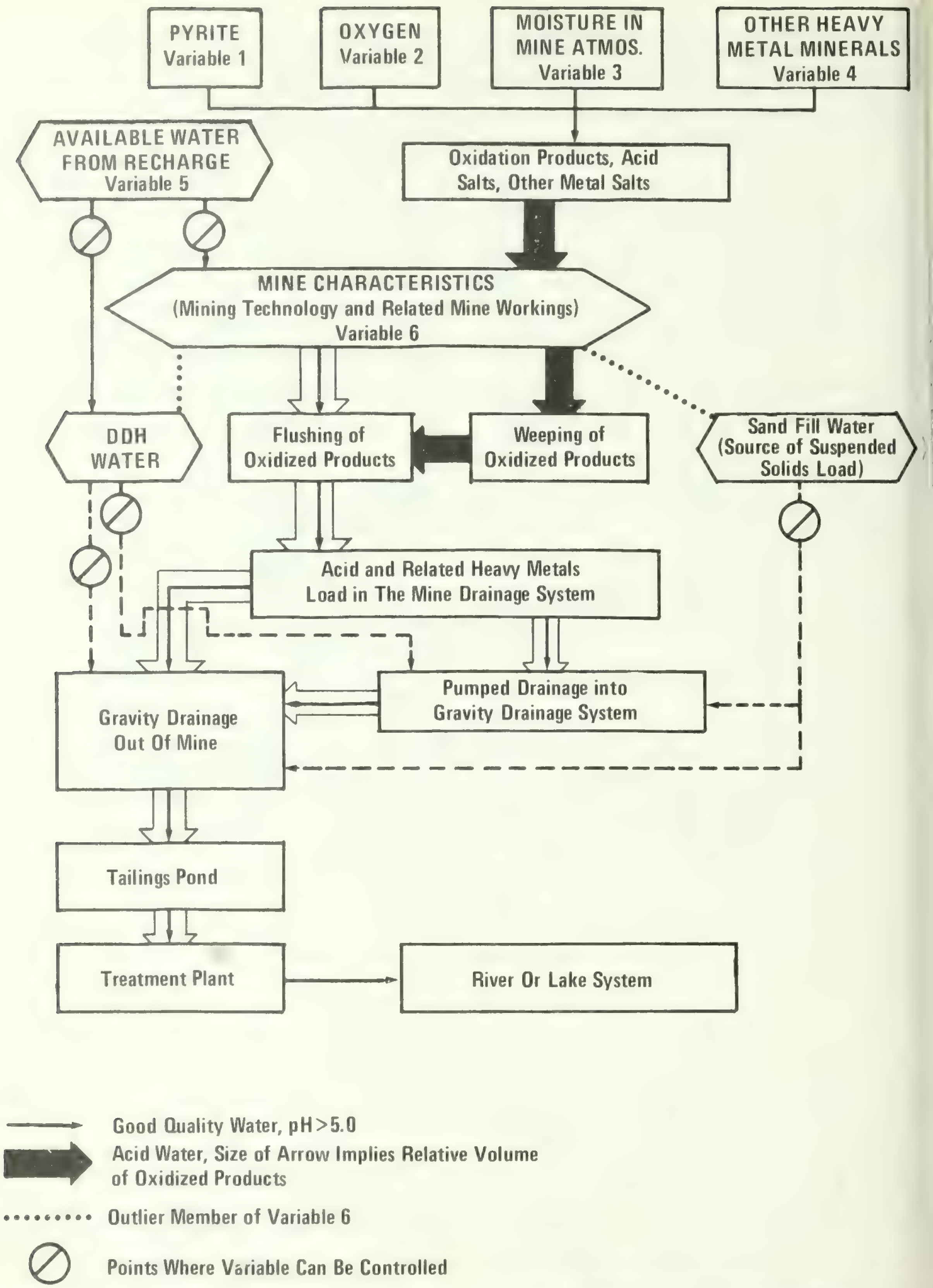

Figure 8. The effect on acid production by controlling variables 5 and 6 (Idaho Bureau of Mines and Geology, Mosco

block caving and open pit ore removal; and (4) constructing sealed channels for streams where mining features underlie the streambeds at shallow depths.

To reduce drainage into the mine from intercepted ground water flow systems, points or zones of water entry into the mine must be identified. These include diamond drill holes, and stopes and drifts that intercept flow in fracture zones and fault fractures. Then, water movement into the mine workings must be reduced by: (1) sealing or plugging all flowing diamond drill holes; and (2) sealing any local stope or drift areas that produce considerable water. Fault fractures may be grouted to seal them.

Methods of improving the quality of mine drainage water include diverting water movement around high acid-producing areas in the mine and limiting the production of acid salts.

Regarding diversion of water movement around acid-producing areas in the mine, first, areas of acid-producing ore or waste rock must be identified. Next, paths of water movement in and near the acid-producing areas must be identified, and then water must be diverted around the acid-producing areas to allow a minimum flushing effect.

Regarding limiting the production of acid salts, oxygen can be eliminated from the mine atmosphere through sealing and/or flooding, or water can be neutralized near the acid-producing areas. To eliminate oxygen from the mine atmosphere, all mine openings or all openings to a given area must be sealed. This will not generally eliminate all oxygen from the mine atmosphere if the host rock is fractured. After sealing lower openings to the mine, the acid-producing area of the mine can be flooded. To neutralize water near the acid-producing areas, the feasibility of this alternative depends on the magnitude of the problem and the characteristics of the underground workings. This may be an alternative that requires renewal after a relatively short period of time.

Alleviation of a mine drainage problem often involves using a combination of several of the techniques mentioned. For example, in a given situation, all identifiable surface recharge to the mine may be minimized; all flowing drill holes may be plugged and high water-producing areas may be sealed off where possible; water around acid-producing areas in the underground working may be diverted to minimize the flushing effect; as much of the mine as possible (without creating many small seep areas) may be flooded; and all remaining discharge may be collected to minimize the number of mine drainage discharge points, a step that eases the cost of discharge treatment.

What other acid mine drainage problems may occur on existing or abandoned mines?

Additional problems connected with solving acid drainage problems on existing or abandoned mines include cost considerations and who has the legal authority and responsibility to deal with the problems.

Discussion:

Regarding costs, acid drainage problems on existing and abandoned mines are very expensive to correct, and money is not available to the Forest Service in most places for solving the problems. Some money, however, may now be available in States with coal; these States can use 50 percent of the money allocated under the Surface Mining Control and Reclamation Act of 1977 (P. L. 95-87, U.S. Code 30-USC 1201) to correct non-coal mine problems after the abandoned coal mines are reclaimed.

Regarding legal authority and responsibility to deal with acid drainage problems, most of the existing problems are on patented lands, so the Forest Service cannot work with the problems; also many of the mines are under court suits or court orders, so no one has the authority to do anything about them. Also, it has not yet been determined who is responsible for correcting problems with abandoned mines or who is legally responsible for pollutant sources, including acid drainage, coming off the land these mines are on.

How can acid drainage problems in new mines be minimized?

It is possible to predict acid drainage problems prior to mining, when an adequate data base is available. The data should include information on the mineralogy, hydrology, and physical characteristics of the mine. Then, when it is known that acid drainage will occur, a controlled environment—one minimizing acid production—can be constructed.

Discussion:

Such a controlled environment would limit the number of transport mechanisms for the acid. In other words, water should exit from the mine as a single treatable discharge. Limiting transport mechanisms is easier underground (where recharge is controllable) than in an open pit, so a company facing the costs of acid drainage control may decide to mine underground based on this consideration. In addition, waste piles for new mines should be located where they can be hydrologically isolated; that is, the surface beneath the wastes can be sealed and the surface of the waste pile can be revegetated. Also, during mining, topsoil and subsoil material should be stockpiled and used later to cap waste piles and other areas after mining is complete.

How can acid drainage from waste materials on the surface be controlled?

Acid drainage from waste piles at abandoned or existing mines can be controlled by surfacing, if acid problems are caused by water leaching down through the wastes and transporting acid. At new mines, acid drainage problems from waste piles can be effectively reduced by putting the wastes in a hydrologically isolated area.

Discussion:

On new, existing, and abandoned mine waste piles, surfacing with at least a foot of innocu material, then establishing as heavy a stand vegetation as possible on a layer of topsoil subsoil, can effectively reduce the oxidation tential of acid-producing materials. According the Environmental Protection Agency exp ments that produced this information, 1 ft the innocuous surfacing material was suffici to reduce oxidation. Where possible, surfac beneath waste piles, as well as on top, helps control acid that may reach streams throu deep seepage.

> **Exception:** There are indications on some sites that acids and heavy metals in waste piles move upward and eliminate the vegetative cover that has been established. In some cases, the vegetative cover deteriorated more year by year. Specific hydrologic information about the movement of the acid in waste piles and about where acid production occurs in waste piles is lacking at this time.

What specific knowledge gaps exist regardi acid mine drainage?

(1) The effects of micro-climatic events continuous low levels of acid production and resulting effects on streams and fisheries are n known.

(2) Methods of tailings pond management, lesign, and location that can best control or ninimize acid mine drainage problems are not nown.

(3) The chemistry of acid production from yrites is not entirely understood; in Eastern oal mines it is known that the nature of the yrites has a tremendous effect on the severity f acid mine drainage problems, but the extent o which this is applicable in the West is not nown.

(4) More information is needed on the gener-l hydrology of acid mine drainage and the role f revegetation and topsoiling in minimizing the roblem of waste piles.

(5) More information is needed about the ranslocation mechanisms of heavy metal salts to ve stream channels.

(6) More information is needed about the atural recovery of streams after they have been lamaged by acid drainage. Information on this is ery limited, and while there have been a few ases where streams have been left alone with ttle restoration effort and they have partially ecovered over time (Rock Creek in Montana, or example), information is not available for making decisions about how to best treat streams for recovery once acid drainage into them is halted.

Discussion:

These knowledge gaps pertain to existing, abandoned, and new mines. While these gaps do not deter efforts to prevent and/or control acid mine drainage, they do indicate that further work needs to be done in this arena.

Additional Information:

For more information about acid mine drainage in high elevations, refer to "Acid Mine Rehabilitation Problems at High Elevations," by Robert S. Johnston, Ray W. Brown, and Jack Cravens, USDA For. Serv., reprinted from the Watershed Management Symposium held by the ASCE Irrigation and Drainage Division, Logan, Utah. August 11-13, 1975.

Figs. 7 and 8 originally appeared in: Trexler, Bryson D., Jr., Dale R. Ralston, Dennis R. Reece, Roy E. Williams, Sources and Causes of Acid Mine Drainage. Dec. 1975. Idaho Bur. of Mines and Geology, Moscow. Pamphlet No. 165.

Chapter 9
IMPOUNDMENTS

hapter Organizer: Grant Davis

lajor Contributor: Clifford Hawkes

During review of the mining plan, the hydrol-gist will be faced with a number of consider-ions regarding impoundment of water on the iining site. The first consideration is whether or ot an impoundment is necessary and legally lowed, and then, if so, what its use will be. If it determined that an impoundment is needed, ie next step is to insure that the impoundment properly designed, operated, and maintained) accomplish its purpose and that these steps e included in the mining plan. The hydrologist ill work closely with the engineer during this eview to insure that the impoundment is con-tructed appropriately and that potential azards, such as overflow and flooding, are mini-iized. This chapter summarizes concerns associ-ted with impoundments. The hydrologist hould refer to the User Guide to Engineering NT-70) in this series for more specific informa-on on sediment basins.

what situations would impoundments be und on mine sites?

Impoundments may be developed on mine tes as a result of mining, removal of the mined aterial (such as coal, bentonite, clay, etc.), or a ecision not to fill the mine pits with spoils. hey may also be deliberately constructed on ine sites to trap and store sediment.

iscussion:

In situations where impoundments occur on ine sites, the most important consideration is) determine an appropriate end-use for these npoundments, and then to insure that that end-se is effectively accomplished. Possible end-uses r such impoundments are as a habitat, food, id nutrient source for various organisms, such fish and wildlife; as a drinking water source for livestock and wildlife; as an irrigation water source; and, occasionally, as a human-recreation source. Regardless of what the end-use is, certain characteristics must be monitored to insure that the planned end-use is accomplished: water quality; basin morphometry (shape of the basin and pond bottom); aquatic plants that may occur or be established at the impoundment; and aquatic invertebrates. Depending on the purpose of the impoundment, these characteristics must be anticipated and monitored to assure that the desired end-use is realized. In many cases, it is possible to reclaim the mining area first, then build the kinds of ponds considered to be desirable.

Additional Information:

For detailed information on the characteristics mentioned above, refer to "Limnological Methods," by Paul S. Welch, McGraw-Hill Book Co., Inc., New York, 1948.

In situations where impoundments are deliberately constructed on mine sites, design must be carefully thought through, taking into account a number of considerations. Even before impoundments are planned, however, it must be decided whether they are necessary. In the case of sediment ponds in particular, the hydrologist should determine when reviewing the mining plan whether a pond is a proper alternative. In other words, he should consider whether sediment can be controlled through other means, such as pitting, slope modification, or materials surfacing (discussed in chapter 6); the sediment basin should be utilized where needed, but, in general, should be considered as a last resort.

What factors should the hydrologist consider in determining the adequacy of the mining plan regarding sediment basins?

Generally, he should consider design criteria; the precipitation characteristics of the area; pre-

dictions of sediment load and quality; location of the basin (on-channel or off-channel); volume of material the basin will have to accommodate; desired water-quality standards; safety; maintenance; post-reclamation plans for the basin; and State water laws regarding impoundment of water.

Discussion:

In each situation, site-specific characteristics determine the final design and operation of the sediment basin; final maintenance requirements are determined by the postmining use of the basin—that is, whether the basin will, in fact, be left on the site, or whether it will be removed. Generally, however, basins should be slightly overdesigned because of the uncertainty hydrologic and meteorologic data. For exam to insure adequate capacity to safely handl 25-yr precipitation event, the basin should designed to accommodate a greater volume t the data might indicate was necessary. Safet a major consideration, since basin failure create hazardous situations.

When reviewing the mining plan for adequ of sediment basin design, the hydrologist sho use the data available to him to predict as curately as possible the requirements for sediment basin. Then, he must work with engineer to determine whether provisions meeting those requirements are included in mining plan.

Chapter 10
POSTMINING CONSIDERATIONS

Chapter Organizer: Grant Davis

Major Contributor: Grant Davis

After reclamation is completed, the Forest Service interdisciplinary team will monitor the mine area to make sure that the reclamation program is effective, and, if problems do arise, to see that they are corrected. If postmining monitoring determines that the mining company has fulfilled its obligation to reclaim the site, then the company can be released from its performance bond. Information provided by the hydrologist will be an important factor in making such decisions.

Since extensive reclamation of minelands has been required of companies for only a short period of time, postmining standards are not very specific. In some cases, such as in coal mining, there are legal requirements, but these are also fairly general. Thus, the land manager will need to set criteria standards for releasing the mining operator from the bond. These standards should appear in detail in the operating plan, although the plan should also include some allowance for variances.

What general principles apply to postmining monitoring?

There are four general principles that should be included in monitoring: the monitoring program should be formulated in the early planning stages of baseline data collection and should be included in the operating plan; monitoring should continue through mining, reclamation and postmining stages; the monitoring program should be adjusted according to the operation phase and data analysis, so that the measurements being taken are cost effective; if any problems are detected through the monitoring program, they should be corrected as soon as possible.

Discussion:

The monitoring plan should be developed to answer specific questions, and it should state what will be monitored and where, who will do the monitoring, how often, and how data will be analyzed statistically and with what methods.

During a long-term operation, different areas of a mine will be in different stages of development. Some areas will not have been mined, some will be active, some will be in a phase of reclamation, and some will be completely reclaimed. Thus, monitoring will occur in different phases, simultaneously.

During the mining and reclamation stages, it might be necessary to include more measurements in the monitoring program than during the postmining stage. As data are analyzed and repeat measurements appear, it might be feasible to reduce the number of items measured, the sampling frequency, and the number of sampling points. For example, if the program originally included monitoring 20 wells, it could be possible to either eliminate certain wells as they stabilize, or to sample them only during periods when the greatest changes are expected to occur.

If monitoring uncovers any problems in reclamation, they should be corrected immediately. Once the performance bond is released, problems that have been neglected become the Forest Service's responsibility.

What factors should be considered during postmining monitoring?

Some of the most important items to consider in a postmining monitoring program are overland flow, streams, subsurface flows, and impoundments.

Discussion:

The water quality and quantity of any discharge from the overland flow should be carefully monitored. A schedule should be set up to include regular monitoring for such items as

streams, wells, and all items listed in the monitoring plan. This schedule should also include visual observation for signs of erosion on the reclaimed area.

When discharge from a mining operation is going into a stream, monitoring should take place both above and below the discharge points. A measurement should also be done on the discharge itself. If a stream has been either reclaimed or relocated, it will need more intensive monitoring, including profiles, information on bedload, bank erosion, and vegetation, as well as the quality and quantity of water in that area.

When monitoring subsurface flows, wells located at strategic points will have been identified in the monitoring program. Checks should be made of water quality, water level, and fluctuations in the ground water level. Other elements that should be measured will depend on the area itself. For instance, if a site has had problems with salinity, or if toxic ions are natural to the area, these items should be monitored. It's also necessary to monitor subsurface flows for seeps, which may come from either overburden or tailings ponds, or in the case of an underground mine, seeps that start to occur as the mine fills with water.

With impoundments, water quality, vegetation that has been established, and sediment buildup should be monitored. If a dam or a spillway is monitored, check for signs of damage or deterioration, such as seeps coming out from below the dam.

What does maintenance management involve once a mine is abandoned?

Once a mine site has been abandoned, such items as impoundments, sediment basins, roads, and diversion ditches must be maintained. . other structures will also require either rem or maintenance.

Discussion:

As in the development stage, during the m tenance program, the hydrologist will be w ing in cooperation with the engineer to main hydrologic structures. Impoundments, sedim basins, risers, and spillways may all need cl ing or repair. Vegetation on the dam sh bychecked regularly and the dam should als examined for seeps, which are a sign of dete ration.

In the case of roads, items that must be m tained are drainage systems, culverts, includ discharge from the culverts, and ditches. pending on the size of the road and the c dition of the area, when bedding down an ab doned road, it may be preferable to remove culverts and grade the road to the outslope, there will not be any ditches. If a road is retained by the mining company, and it has been accepted by the Forest Service or County, then it should be abandoned to av maintenance costs.

After a mining operation is closed, divers ditches may also have to be maintained if th go around acid piles or cut through long slo to break up erosion patterns.

Additional Information:

For more information about hydrologic d collection, refer to Barrett, James and othe 1979. "Procedures Recommended for Ov burden and Hydrologic Studies of Surf Mines, Thunder Basin Project." USDA For. Se Gen. Tech. Rep. INT-71. (In Press)

For additional information on hydrolo monitoring, refer to chapter 2530 of the For Service Manual, "Hydrologic Surveys, Prescr tions, and Plans."

APPENDIX A

GLOSSARY

lluvium: Material, including clay, silt, sand, avel, and mud, deposited by flowing water.

quifer: A geologic formation or structure that ansmits water. Aquifers are usually saturated nds, gravel, fractured rock, or cavernous rock.

aseline data: Data gathered prior to mining for ie purpose of outlining conditions existing on ie undisturbed site. Reclamation success is ieasured against baseline data.

ritical area: An area that should not be disırbed (i.e., mined) because it is deemed exemely difficult or impossible to reclaim.

ischarge: The volume of water flowing past a oint per unit time, commonly expressed as ıbic feet per second, million gallons per day, allons per minute, or cubic meters per second.

nvironmental Assessment (EA): A report on nvironmental effects of proposed Federal ctions, which may require an Environmental npact Statement (EIS) under section 102 of ie National Environmental Policy Act (NEPA) f 1969. The EA is an "in-house" document of arying degrees of formality; it becomes the nal document on environmental impacts for iose projects which, because their effects are iinor, do not require a formal EIS. Although ot formally prescribed under NEPA, the EA is ie document normally used to determine hether section 102 of NEPA applies to the proct in question and as such, is subject to court iallenge if no EIS is filed.

nvironmental Impact Statement (EIS): A docuient prepared by a Federal agency in which ancipated environmental effects of a planned ourse of action or development are evaluated, s prescribed by the National Environmental olicy Act (NEPA) of 1969.

rosion: The group of processes whereby earthy r rock material is worn away, loosened or disılved, and removed from any part of the earth's ırface. It includes the processes of weathering, solution, corrosion, and transportation. "Erosion" is often classified by the eroding agent (wind, water, wave, or raindrop erosion) and/or by the appearance of the erosion (sheet, rill, or gully erosion) and/or by the location of the erosional activity (surface or shoreline) or by the material being eroded (soil erosion or beach erosion).

Evapotranspiration: Moisture that is drawn off the soil in the form of a vapor.

Feasibility study: As applied to mining, the feasibility study follows discovery of the mineral and is done by the mining company. Its purpose is to analyze the rate of return that can be expected from the mine at a certain rate of production. Based on this study, the decision to develop the ore body may be made.

Fishery: Any premises upon which breeding, hatching, or fish-rearing facilities are situated when such premises are required to have a license by the State fish and game code, including ponds for commercial use.

French drain: A trench loosely backfilled with stones, the largest stones at the bottom and the size decreasing toward the top. The spaces between the stones serve as a passageway for the water.

Ground water: Water within the earth that is in the zone of saturation where all openings in soils and rocks are filled—the upper surface of which forms the water table; water that supplies wells and springs.

Hydraulic conductivity: The rate of water flow through a porous medium. Also referred to as the coefficient of permeability. Derived from Darcy's Law and expresses flow velocity, v, as the product of the coefficient of permeability, k, and the hydraulic gradient, dh/dl.

Hydraulic resistance: The ability of water under pressure to retard motion.

Hydrograph: A graph showing variation in the water depth in a stream or the volume of water flowing past a point in a stream over a period of time.

Hydrologic budget: An important concept in surface-mine reclamation is "hydrologic budget," which refers to the amount of water entering an area (by precipitation, stream flow, aquifer flow, runoff), in relation to the amount leaving the area (by stream flow, aquifer flow, evaporation, and transpiration).

Hydrologic cycle: The circuit of water movement from the atmosphere through various stages or processes on the ground and then back to the atmosphere again by evaporation and transpiration (also called water cycle).

Hydrolyzation: To decompose a chemical compound by reaction with water.

Impoundment: The accumulation of any form of water in a reservoir or other storage area.

Infiltration: The movement of water into the soil through pores or other openings.

Interdisciplinary team (ID Team): As proposed by recent Forest Service regulations, the interdisciplinary team will be comprised of Forest Service personnel who collectively represent two or more areas of specialized technical knowledge about natural-resources management applicable to the area being planned. The team will consider problems collectively, rather than separate concerns along disciplinary lines. This interaction will insure systematic, integrated considerations of physical, biological, economic, and other sciences.

Laminar flow: Nonturbulent flow of a fluid that has resistance to flow in layers near a boundary.

Land-management plan: According to Forest Service regulations, each forest must have a forest plan, which outlines the most desired and alternative land uses for that site.

Manning's n: An empirically derived estimate of the relative roughness of a channel. Manning's n is used to calculate uniform flow when combined with channel dimensions and ch[illegible] slope.

Mine road: A road constructed for a mi[illegible] operation.

Mining plan: Submitted by the mining ope[illegible] the mining plan outlines the steps the mi[illegible] company will take to mine and reclaim th[illegible] The mining plan is submitted prior to start-[illegible] mining operations.

Monitoring: In regard to disturbances caus[illegible] mining, the site must be carefully observe[illegible] Forest Service personnel to insure that rec[illegible]tion goals are being met.

Mulching: Placing or leaving non-living ma[illegible] on or near the soil surface for the purpo[illegible] protecting the surface from erosion or pro[illegible]ing plants from heat, cold, or drought.

Overburden: Material overlying a deposit of [illegible]ful materials, ores, or coal, up to, but not in[illegible]ing, the topsoil.

Overland flow: The thin layer of water [illegible] flows over the ground surface as a result [illegible] rainstorm or snowmelt runoff.

Oxidation: The combination of substances [illegible] oxygen. If the substance is a sulfide, this o[illegible]tion may result in an acidic conditon.

Patented lands: Land to which a patent has [illegible] secured from the Government by compli[illegible] with the laws relating to such lands. The pa[illegible] is a legal document which conveys the titl[illegible] the ground to the land's owner.

Percolation: The downward movement of w[illegible] within a soil, especially the downward flo[illegible] water in saturated or nearly saturated soil.

pH: Symbol for the negative common logari[illegible] of the hydrogen-ion concentration (acidity) [illegible] solution. The pH scale runs from 0-14. A p[illegible] about 7 is considered neutral. A pH number [illegible]low 7 is acidic and a pH value above 7 is alka[illegible] or basic.

Piezometric surface: An imaginary surface c[illegible]

ing with the hydraulic pressure level of the ter in a confined aquifer, or the surface coin- ing with the water level in observation wells. ntour maps or cross-sections of a piezometric face or the water table can show the direction ground water flow.

cipitation: Any form of rain or snow.

cipitation index: A table describing the tern of rain or snowfall.

charge: The addition to an aquifer of water t occurs naturally from infiltration of rainfall l from water flowing over earth materials that w water to infiltrate below the land surface.

-rap: A loose assemblage of broken rock ced to protect soil from the forces of erosion from movement due to excess hydrostatic ces.

nity: The amount of salts in the soil or er.

iment: Solid material, both mineral and or- ic, that is in suspension, is being transported, has been moved from its site of origin by air, er, gravity, or ice and has come to rest on the th's surface either above or below sea level.

iment basin: A pond, depression, or other ice used to trap and hold sediment.

mping: A sudden sliding or sinking of the es of a mine dump caused by the ground er reaching a level of saturation.

w fences: Temporary fencing composed of upright slats used to prevent snow from im- ing access to a mine site. Snow fences can provide a means for accumulating and stor- water.

Soil: The loose surface material of the earth, usually consisting of disintegrated rock and a mixture of organic matter and soluble salts.

Spoils: Any dirt or rock which has been removed from its original location by mining operations.

Surface runoff: The moisture that is not absorbed by the soil.

Terracing: Creating a series of raised banks of earth to reduce effective slope length. Sometimes terracing can help prevent severe rill and gully erosion.

Transmissivity (coefficient of): A measure of the permeability of an aquifer. It is expressed in English units as gallons per square feet per day.

Universal Soil Loss Equation: An equation used for the design of water erosion control systems. A=RKLSPC wherein A=average annual soil loss in tons per acre per year; R=rainfall factor; K=soil erodibility factor; L=length of slope; S=percent of slope; P=conservation practive factor; and C=cropping and management factor.

Water balance: A measure of continuity of flow of water, and may be used for any time interval, any drainage basin, or for the earth as a whole. The water balance equation may be written as: E=I-O-S, where E is evaporation; I is inflow, or precipitation; O is outflow, or total runoff; and S is the change in reservoir contents.

Watershed: The total area above a given point on a stream that contributes water to the flow at that point.

Water table: The upper surface of the ground water or that depth below which the soil is saturated with water.

APPENDIX B

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USDA Forest Service 1979. User guide to hydrology. USDA For. Serv. Gen. Tech. Rep. INT-74, 64 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Summarizes and discusses key questions and rules the hydrologist should consider when working in mining area reclamation. Topics include land-management planning, exploration, and baseline data and the mining plan; surface water; subsurface water; snow management; roads; effects of reclamation on surface water; subsurface water management and treatment; acid mine drainage; impoundments; and postmining considerations.

KEYWORDS: hydrology, mining, mining area reclamation, mining area rehabilitation, land-management planning process.

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THE SEAM PROGRAM

The Surface Environment and Mining Program, known as SEAM, was established by the Forest Service to research, develop, and apply new technology to help maintain a quality environment while helping meet the Nation's mineral requirements. SEAM is a partnership of researchers, land managers, mining industries, universities, and political jurisdictions at all levels.

Although the SEAM Program was assigned to the Intermountain Station, some of its research projects were administered by the Rocky Mountain and Pacific Southwest Research Stations.

MINERAL USER GUIDES

Other User Guides for specialists involved in minerals activities are:

- User Guide to Vegetation, Gen. Tech. Rep., INT-64
- User Guide to Soils, Gen. Tech. Rep., INT-68
- User Guide to Engineering, Gen. Tech. Rep., INT-70
- User Guide to Sociology and Economics, Gen. Tech. Rep., INT-73
- User Guide for Wildlife (planned)
- User Guide for Visual Management (to be published as part of the National Forest Landscape Management Series)

To obtain copies of these guides, write: Intermountain Forest and Range Experiment Station, USDA Forest Service, 507 25th St., Ogden, UT 84401.

GENETIC VARIATION IN SOUTHERN IDAHO PONDEROSA PINE PROGENY TESTS AFTER 11 YEARS

Gerald E. Rehfeldt

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FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION

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RESEARCH SUMMARY

Comparisons were made among 268 half-sib families of ponderosa pine from 37 southwest Idaho populations at four test sites. Data involved 8- and 11-year height, the percentage of trees damaged by snow, and the percentage of trees with straight stems. Analyses of variance evidenced population differentiation for height at both ages but not for the percentages of snow-damaged or straight-stemmed trees. Differences among populations accounted for about 20 percent of the genetic variance; most of the genetic variance occurred within populations.

Multiple regression analyses were made to relate population differentiation to geographic and ecologic variables. The data suggested that elevation of the seed source controlled differentiation; latitude and longitude were secondary; and habitat types were not important. From these results, it was concluded that seed for afforestation should not be transferred more than 450 m elevation, 1.7 degrees longitude, and 2.2 degrees latitude.

Quantitative genetic analyses provided estimates of family heritabilities in 11-year height that ranged from 0.37 to 0.53 for the various planting sites. These heritabilities imply that genetic gains of about 7 percent can be expected readily in the 11-year height of progenies of selected families.

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INTRODUCTION

Tree improvement offers genetic gains at three levels. First, by accounting for ecological adaptations of populations, seed zones limit losses in productivity from maladaptation. Second, progeny tests identify individual trees and populations of exceptional characteristics for siring subsequent generations. And third, intensive tree improvement provides maximal genetic gains in productivity through matings of select families within adaptated populations. Gains at the first two levels are readily realized. But, realization of the potential genetic gains begins with the yield of genetically improved seeds from seed orchards developed from parentage of known performance.

During the last 15 years, a practical tree improvement program has been developed for ponderosa pine (*Pinus ponderosa*) in southwestern Idaho. As explained previously Wang 1967; Wang and Patee 1974, 1976), the program was begun to assess the genetic ains expected to accrue from seed zoning, from population selections within zones, nd from family selections within populations; and to provide materials and information rerequisite to the establishment of seed orchards.

Because of a high economic value, tree improvement of ponderosa pine has received onsiderable attention. As reviewed by Wang (1977), genetics research was begun arly in the twentieth century. Today, numerous research programs annually update nd augment the genetics literature of the species. In fact, practical tree improve-ent programs exist in nearly every state included by the species' natural range. In ddition, ponderosa pine has been subject to domestication programs in Europe, ustralia, and eastern North America.

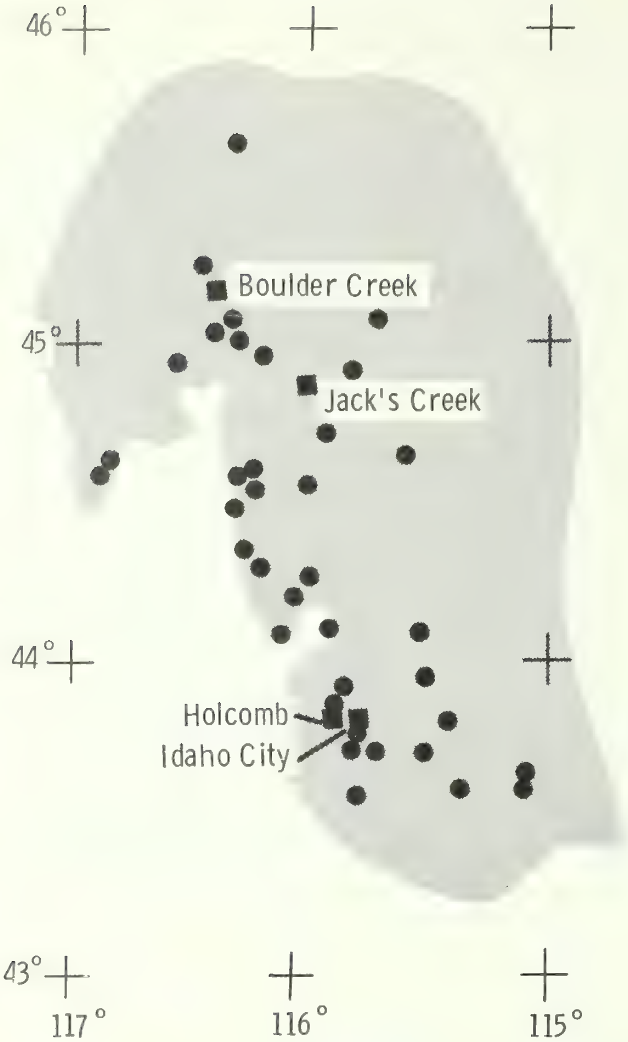
The present report assesses the performance of progenies included in the southwest daho tree improvement program, a cooperative of federal, state, and private forest rganizations. The performance of progenies at ages 8 and 11 is related to gains nticipated in an intensive tree improvement program.

MATERIALS AND METHODS

Since procedures of cone collections and plantation establishment have been ocumented (Wang and Patee 1976), a brief summary will suffice. Wind-pollinated ones were collected from 1 to 10 trees in each of 37 populations (fig. 1). Popula-ions were separated by about 2 degrees in latitude and longitude. Within this area, ost of the ecological amplitude of the species was represented. Populations were rom elevations as low as 975 m and as high as 1 980 m. Habitat types varied from e relatively dry *Pinus ponderosa/Purshia tridentata* to the relatively moist *Abies randis/Vaccinium globulare*.

Two-year-old seedlings from 268 families were planted in 4-tree row plots in 10 plicates at 4 planting sites. About 1.5 m separated trees within rows; 3 m separated ows. Test sites (fig. 1) included Idaho City (1 200 m elevation), Holcomb (1 100 m), oulder Creek (1 450 m) and Jack's Creek (1 650 m).

Figure 1.--Location of populati
(dots) and test sites (squar
shaded area represents distr
tion of forested lands.



Measurements of the height of individual trees had been made at ages 8 and 11. At age 11, stem straightness was also scored on a scale of 1 to 4: 1 = straight stem, 4 = severe crook. In addition, injuries to each tree were classified as the presence or absence of damage from rodents, insects, disease, snow, water and large mammals.

Statistical analyses were made to estimate genetic components of variance in the height of progenies at ages 8 and 11. Tests of chi-square were used to assess stem straightness and snow damage to trees at Boulder Creek. Only data from Boulder Creek were included in the latter analyses because scores of stem straightness and injuries were either invariate or randomly distributed at the other test sites; damage from snow was exceptionally high at Boulder Creek. Finally, multiple regression analyses were used to relate population differentiation to geographic and ecologic variables of the seed source.

RESULTS

Analyses of variance were made according to a least squares fit to the model resented in table 1 for height at ages 8 and 11. Similar analyses were made for a easure of growth rate between ages 8 and 11 where growth rate was expressed as the eviation from regression of 11-year height on 8-year height. But the relationship etween height at the two ages was so strong ($r = 0.89$) that deviations from regression ere essentially randomly distributed. Since no genetic effects were apparent in nalyses of growth rate, results of analyses are not presented.

Analyses were made separately for data from each plantation. Separate analyses ere necessary because of an extreme imbalance in the representation of families mong replicates and planting sites. Imbalances in the original design had been onfounded further by survival percentages of 22, 42, 63 and 80 percent at Jack's reek, Holcolmb, Idaho City, and Boulder Creek, respectively. Consequently, many amilies were not represented in all replicates at any planting site. And more nportantly, several families were not represented at all planting sites. The esultant imbalance precluded calculation of unbiased least squares estimates and eightings for variance components involving interactions of families and planting ites.

Table 1.--*Form of the analyses of variance and expected mean squares*

Source of variance	Expected mean squares[2]
Replications	$\sigma^2_{E_1} + \sigma^2_{E_2} + k_4\sigma^2_{T/P} + k_6\sigma^2_P + k_7\sigma^2_R$
Populations	$\sigma^2_{E_1} + \sigma^2_{E_2} + k_3\sigma^2_{T/P} + k_5\sigma^2_P$
Trees/Populations	$\sigma^2_{E_1} + \sigma^2_{E_2} + k_2\sigma^2_{T/P}$
Experimental Error[1]	$\sigma^2_{E_1} + \sigma^2_{E_2}$
Within	$\sigma^2_{E_1} = \sigma^2_W/k_1$

[1]Contains all sources of variation involving interactions of replication

[2]where:

	Holcomb	Idaho City	Boulder Creek	Jack's Creek
k_1 =	1.79	1.88	2.79	1.51
k_2 =	6.06	8.09	7.93	3.71
k_3 =	6.71	8.54	8.53	4.44
k_4 =	.36	.19	.20	.66
k_5 =	41.79	57.47	54.91	25.78
k_6 =	.06	.01	.11	.13
k_7 =	161.30	213.47	215.15	94.84

Although mortality was generally high, little can be attributed to environmental maladaptation. Most death occurred within 2 years after planting. Whereas pocket gophers accounted for the high mortality at Jack's Creek and Holcomb, root rots were prevalent at Idaho City. Since more than 8,000 trees were planted at each site, even high levels of mortality could be absorbed without complete invalidation of statistical analyses. Thus, high mortality should have negligible effects on the interpretation of results.

Results of the analyses of variance (table 2) indicate statistical significance for all sources of variance at each planting site. Main interest for tree improvement, however, involves the genetic variances associated with the effects of populations and effects of maternal trees within populations. Whereas the former effects reflect population differentiation on which seed zoning relies, the latter represent the inheritable differences among families on which intensive tree improvement programs are based. Depending on tree age and planting site, effects of populations account for 8 to 35 percent of the genetic variance (table 3). Thus, most of the genetic variance exists within populations.

Table 2.--*Results of analyses of variance for each location. Variance components (σ^2) are derived according to Table 1*

Source of variance	Height at age					
	Eight			Eleven		
	d.f.	Mean Square	[illegible]	d.f.	Mean Square	[illegible]
[illegible]						
Replication	9	7366**	43	9	24982**	148
Populations	36	920**	7	36	2217**	14
Trees/pops.	227	601**	44	227	1571**	83
Expt. Error	1355	335**	125	1363	1069**	448
Within	2244	210	[1][illegible]	2236	620	[1]1110
Idaho City						
Replication	9	8291**	37	9	23851**	107
Populations	36	1541**	15	36	3413**	30
Trees/pops.	225	660**	33	225	1666**	84
Expt. Error	1875	396**	124	1864	987**	403
Within	3006	272	[1]511	3024	584	[1]1098
Boulder Creek						
Replication	9	6316**	27	9	18735**	82
Populations	36	1571**	15	36	3489**	33
Trees/pops.	231	698**	38	231	1631**	65
Expt. Error	1869	394**	225	1879	1112**	663
Within	1931	169	[1][illegible]	4924	448	[1]1250
Jack's Creek						
Replication	9	6333**	61	9	42508**	426
Populations	36	1238**	19	36	3381**	19
Trees/pops.	221	699**	61	221	2726**	217
Expt. Error	639	474**	109	717	1921**	682
Within	944	364	[1][illegible]	949	1239	[1][illegible]

**Statistically significant at the 1 percent level of probability.
[1]σ^2_w as defined in table 1.

Table 3.--*Ratios of genetic components of variance. Symbols are defined in table 1*

	Proportion genetic variance attributable to populations: $\frac{\sigma^2_P}{\sigma^2_P + \sigma^2_{T/P}}$	
Location	Age eight	Age eleven
Holcomb	0.14	0.15
Idaho City	.32	.26
Boulder Creek	.29	.34
Jack's Creek	.24	.08

Variance components were also used to estimate family heritabilities, ratios of the additive genetic variance to the total phenotypic variance (table 4). Heritabilities were used to estimate expected response to half-sib family selection (Falconer 1960) and the percent gain expected next generation if present plantations are rogued at two intensities. Values of h^2 presented in table 4, however, are subject to conflicting sources of error. On one hand, progenies of wind-pollinated wild trees are expected to be slightly more closely related than actual half-sibs (Namkoong 1966); thus, present methods of calculation overestimate actual heritabilities. But conversely, part of the variance among populations in these tests reflects differential ecological adaptations. To the extent that maladaptations have reduced the potential variance among populations, estimates of additive genetic variances and heritabilities are deflated.

Finally, estimates of the additive genetic variance from single planting sites are confounded by interactions of genotype and environment (Namkoong and others 1966). But, genetic gains for ponderosa pine in Idaho will accrue within seed zones which still have not been delineated. Appropriate calculations of heritabilities should include inflation of additive genetic variances by genotype-environment interactions (Namkoong 1979). Consequently, the heritabilities presented in table 4 are appropriate if one assumes that each test site represents an individual seed zone.

Thus, even though estimates of heritabilities are subject to conflicting sources of bias, values are likely approximate. Consequently, if 70 percent of the shortest families are rogued at each planting, a subsequent population produced from the remaining 30 percent should realize a gain over the unselected population of at least [illegible] percent in 11-year height (table 4). Again because of excessive mortality, values from the Jack's Creek planting are subject to greatest bias.

Table 4.--*Estimates of family heritabilities, predicted responses to half-sib family selection, and expected gains*[1]

Location		Family heritability h^2	Response to selection (R) at culling levels of		Gain next generation from culling at	
			50%	70%	50%	70%
			----------*cm*----------		------*Percent*------	
Holcomb:	age 8	0.57	9.1	12.9	12	17
	age 11	.44	6.4	9.6	5	7
Idaho City:	age 8	.45	3.8	5.7	5	7
	age 11	.46	6.1	8.8	5	7
Boulder Creek:	age 8	.49	4.2	5.9	5	7
	age 11	.37	4.8	6.9	4	5
Jack's Creek:	age 8	.56	7.6	11.4	12	18
	age 11	.53	14.1	21.2	11	16

[1]Calculations followed Falconer (1960) and Namkoong (1979).

Heavy snow accumulations at Boulder Creek resulted in damage to stems of 69 percent of the trees. In order to determine if families or populations differed in ability to withstand snow accumulations, chi-square analyses were made on the number of individuals within families that exhibited straight stems and on the number of individuals that suffered snow damage. Since families had been established in 4-tree row plots, analyses were made without regard to replication. Family means for the percentage of trees with straight stems varied from 0 to 100; but population means ranged from 6 to 41 percent. Analyses of chi-square showed that families differed significantly at the 1 percent level of probability (X^2 = 341.9 with 268 d.f.); however, no differences could be detected among populations (X^2 = 32.8 with 36 d.f.). Since the correlation among family means for the percentage of trees damaged by snow with the percentage of trees with straight stems was -0.82, chi-square analyses for snow damage also indicated significant differences among families but no differences among populations. And, contrary to results of a provenance study in northern Idaho (Rehfeldt and Cox 1975), there was no indication that trees with the slowest growth rates suffered the least damage: the correlation between mean family height at age 11 and proportion of trees damaged by snow was a nonsignificant value of -0.07. Snow damage at Boulder Creek, however, was so high that subtle differences among families and populations remain undetected.

Population differentiation provides the basis for developing seed transfer rules for afforestation; however, to assess differentiation according to geographic and ecologic conditions of the seed source required mean values for each population at each planting site were required. But, all families and populations were not represented in all replicates in each planting, and replicates had significant effects on performance (table 2). Thus, mean values were confounded by the effects of replication. Effects of confounding were reduced by adjusting plot means for replication before population means were calculated:

$$\hat{Y}_{ijk} = \bar{X}_{ijk} - \bar{X}_{.jk} + \bar{X}_{..k} \quad ;$$

where,

$\bar{X}_{ijk}$ = plot mean for family i of replicate j of plantation k,

$\bar{X}_{.jk}$ = mean value for replicate j of plantation k,

$\bar{X}_{..k}$ = mean value for planting k,

$\hat{Y}_{ijk}$ = adjusted plot means.

Then, differentiation of populations in relation to geographic and ecologic conditions of the seed source was assessed by multiple regression models:

$$\hat{Y}_{ij} = b_o + b_1X_{1i} + b_2X_{2i} + b_3X_{3i} \quad ;$$

where,

$\hat{Y}_{ij}$ = mean value adjusted for effects of replication for population i at planting j,

X_{1i} = elevation at the origin of population i,

X_{2i} = latitude at the origin of population i,

X_{3i} = longitude at the origin of population i.

Results of regression analyses are presented in table 5 for height at ages 8 and 11. Similar analyses were made on the percentage of trees with straight stems and the percentage of trees damaged by snow for each population represented at Boulder Creek. That neither of the last two models was statistically significant is depicted by a lack of significance of simple correlation coefficients involving these two independent variables and the dependent variables (table 6). Since population differentiation was not reflected in the percentages of straight-stemmed and snow-damaged trees, results of multiple regression analyses are not presented.

Table 5 shows that regression models for both ages at all planting sites were statistically significant and accounted for 24 to 41 percent of the variance among populations. Whereas elevation of the seed source had strong negative influences on mean height of populations, latitude and longitude had positive influences; these relationships were also apparent in simple correlation coefficients (table 6). Standardized partial regression coefficients, which reflect the relative importance of the independent variables in determining the dependent variable, suggest that population differentiation is controlled primarily by elevation (table 5). Strong relationships between elevation and population differentiation have also been observed for ponderosa pine in California (Callaham and Liddicoet 1961) and in northern Idaho and western Montana (Madsen and Blake 1977).

Yet, multiple regression models accounted for less than half of the variance among populations. Indeed, 60 to 75 percent of the variance was unexplained. Two of the many possible sources of extraneous variance include an incomplete model and interrelationships among variables that deviated from the linear. In regard to the latter possibility, a visual examination of relationships between residuals from regression and the independent variables did not support transformation of independent variables. And, even though it would be nearly impossible to develop a model that includes all relevant independent variables, additional analyses were made to incorporate habitat types (recurring climax plant communities) into the model presented above. The 37 populations represented 7 individual habitat types and 3 major series of habitat types. The regression model presented previously was adjusted by including a constant term for each habitat type represented; separate models were fitted for individual habitat types or series' of habitat types. However, models in which habitat types were included as constant terms reduced significant models (table 5) to insignificance, primarily because habitat types absorbed six degrees of freedom but accounted for no variance in addition to that already explained by previous models.

That habitat types did not account for variance additional to that associated with latitude, longitude and elevation is illustrated by simple relationships among variables (table 6). Neither the series of habitat types nor individual habitat types were significantly associated with the mean height of populations at any planting site. Yet, even though relationships are insignificant, individual habitat types accounted for relatively large proportions of variance in mean height of populations. However, these relationships seem to be mediated indirectly through strong relationships of habitat types with elevation and latitude, two variables closely associated with the dependent variables. Apparently habitat types do not contribute directly to differentiation of populations, a conclusion quite similar to those for Douglas-fir in both western Oregon (Campbell and Franklin in press) and northern Idaho (Rehfeldt 1979).

Table 5.--*Results of multiple regression analyses presented in terms of regression coefficients (b) and standardized partial regression coefficients (b')*

Variable	Holcomb b	Holcomb b'	Idaho City b	Idaho City b'	Boulder Creek b	Boulder Creek b'	Jack's Creek b	Jack's Creek b'
A. Height at age eight								
X_1 Elevation	-0.220	-0.38	-0.230	-0.33	-0.352	-0.47	-0.388	-0.45
X_2 Latitude	2.679	.31	2.589	.24	.674	.06	3.867	[illegible]
X_3 Longitude	1.356	.12	2.424	.17	1.087	.07	-.602	-.03
b_0	68.07		62.43		90 92		72.11	
R^2		.39**		.33**		.28*		.34**
$s^2_{y.x}$	15.28		24.65		30.45		36.78	
B. Height at age eleven								
X_1 Elevation	-.466	-.50	-.313	-.29	-.347	-.33	-.438	-.31
X_2 Latitude	3.366	.24	3.360	.20	1.274	.08	4.235	.20
X_3 Longitude	1.163	.06	5.337	.25	3.703	.18	5.287	.19
b_0	138.83		100.44		124.50		95.58	
R^2		.41**		.33**		.24*		.29*
$s^2_{y.x}$	38.33		59.93		60.79		108.81	

Table 6.--*Simple linear relationships among independent variables and between independent and dependent variables. Double and single asterisks code statistical significance at the 5 percent and 1 percent levels of probability, respectively*

Variable	Latitude	Longitude	Elevation	Habitat classification Series	Habitat classification Type
	r			r	
Latitude		0.46**	-0.27	0.30*	0.67**
Elevation			-.44**	.09	.46
Boulder Creek					
8-yr. height	0.22	.31	-.52**	.07	[illegible]
11-yr. height	.26	.38*	-.44**	.03	.14
% straight stems	0	-.11	.16	.09	.11
% snow damage	-.16	-.16	-.04	.28	.30
Holcomb					
8-yr. height	.46**	.43**	-.52**	.05	.32
11-yr. height	.41**	.39*	-.59**	.10	.34
Idaho City					
8-yr. height	.41*	.43*	-.47**	.03	.34
11-yr. height	.39*	.47**	-.45**	.03	.27
Jack's Creek					
8-yr. height	.40*	.30	-.51**	.07	.47
11-yr. height	.37*	.41*	-.44**	.05	.32

DISCUSSION

Results have illustrated considerable genetic diversity among and within ponderosa pine populations of southwest Idaho. Consequently, programs of tree improvement can offer genetic gains from seed zoning, population selection within zones, and family selection within populations. Yet, realization of gains in productivity requires that improved genotypes are adapted to environments in which they will be planted. Thus, actual gains will occur within seed zones or breeding units, geographic and ecologic stratifications of forest regions into units within which trees are similarly adapted.

Development of seed zones from the present results follows procedures used for Douglas-fir in north Idaho (Rehfeldt 1979). Accordingly, analyses of variance allow calculation of mean differences among populations that are associated with least significant differences (*lsd*) at various levels of probability (Steel and Torrie 1960). Then, multiple regression models were used to calculate the distances in latitude, longitude and elevation required to alter dependent variables an amount equal to the least significant differences derived above. Geographic distances associated with mean differences among populations that are significant at $lsd_{0.8}$ are given in table 7. As argued previously, a relatively low level of probability (0.8) seems intuitively conservative for avoiding the error of accepting no differences among populations when differences actually exist.

If the minimum geographic distances of table 7 are accepted for limiting seed transfer, ponderosa pine seeds in southwest Idaho should not be transferred more than 450 m elevation, 1.7 degrees longitude or 2.2 degrees latitude. This suggests that for the area under study (fig. 1) seed can be transferred without regard to longitude or latitude; zones can be based exclusively on elevation.

Table 7.--*Geographic distances associated with mean differences among seed sources that correspond to a significance level of 80 percent*

	Holcomb	Idaho City	Boulder Creek	Jack's Creek
A. Height at age eight				
Elevation (m)	900	778	459	790
Latitude (degrees)	2.4	2.2	7.8	2.6
Longitude (degrees)	4.9	2.4	4.9	16.7
B. Height at age eleven				
Elevation (m)	687	910	713	1382
Latitude (degrees)	3.1	2.7	6.3	4.7
Longitude (degrees)	9.1	1.7	2.1	3.7

Even though the limits of seed transfer suggested by the present results are more restrictive than those recommended for western white pine (Steinhoff 1979) and are more liberal than those suggested for Douglas-fir in north Idaho (Rehfeldt 1979), they should be regarded as preliminary. Present techniques relied on statistical detection of differences among populations. Since error variances were relatively high, statistical power tended to be low. Moreover, seed zones must involve numerous adaptational features. In addition to analyses of tree height, corroborative data are necessary on variables such as phenology and cold hardiness before limits of seed transfer are finalized. Nevertheless, there is little doubt that losses in productivity from maladaptation can be reduced by seed zoning in reforestation.

Realization of potential genetic gains begin with the yield of genetically improved seeds from seed orchards. Original objectives of the current improvement program included possibilities of converting half-sib progeny tests to seed orchards. Indeed, a gain of at least 7 percent can be expected in 11-year height of progenies from the current plantings after 70 percent of the shortest families are removed. But, if it is assumed that each planting site represents a seed zone of the size suggested above, only one-third to one-half of the 37 populations would actually represent the zone associated with each planting site. Consequently, if the present plantings are rogued first according to seed zones and secondly according to performance, the genetic base may be depleted such that the desirability of seed orchards is questionable.

Current test plantations will yield data from 16-year-old trees before thinning is necessary. The next data set will best address future objectives of current progeny tests. But more importantly, future data will allow comparison with results obtained with ponderosa pine in California: mean differences among families changed greatly between ages 20 and 25 (Namkoong and Conkle 1976). If applicable to the same species in Idaho, the California results imply that family evaluations should be delayed as long as possible.

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Comparisons of the 8- and 11-year heights among progenies from 268 half-sib families of ponderosa pine from 37 southwest Idaho populations were made on four test sites. Multiple regression analyses suggested that seed for afforestation should not be transferred more than 450 m elevation, 1.7 degrees longitude, and 2.2 degrees latitude. Habitat types can be neglected in seed zoning. Quantitative genetic analyses provided estimates of family heritabilities in 11-year height that ranged from 0.37 to 0.53 for the various planting sites. Consequently, genetic gains of about 7 percent can be expected readily in the height of 11-year-old progenies from selected families.

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